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EVALUATION OF NICKEL-HYDROGEN BATTERY FOR SPACE APPLICATION

J. M. Billard and D. Dupont

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16. Abstract

Results of electrical space qualification tests of nickel-hydrogen battery type HR 23S are presented. The results obtained for the nickel-cadmium battery type VO 23S are similar except that the voltage level and the charge conservation characteristics vary significantly. The electrical and thermal characteristics permit predictions of the following optimal applications: charge coefficient in the order of 1.3 to 1.4 at 20C; charge current density higher than C/10 at 20C; discharge current density from C/10 to C/3 at 20C; maximum discharge temperature: 0C; storage temperature: -20C.

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EVALUATION OF A NICKEL-HYDROGEN BATTERY FOR SPACE APPLICATION

FINAL REPORT

OCTOBER 1975

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for

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SUMMARY

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The results obtained at the time of the space qualification electrical tests on the $Ni-H_2$ battery, HR 23S are uniform with those obtained on the Ni-Cd battery VO 23S.

Only the voltage level and the characteristics of charge preservation show significant differences.

The electrical and thermal characteristics lead to the expectation that the optimum ranges of use will be as follows:

- charge coefficient on the order of 1.3-1.4 at $20^{o}C$
- maximum amperage of charging current of C/10 at $20^{o}C$
- amperage of discharge of C/10 to C/3 at $20^{o}C$
- optimum discharge temperature: $0^{o}C$
- storage temperature: $-20^{o}C$

It is adviseable to note that these results apply to the $Ni-H_2$ battery, HR 23S manufactured in conformity with Document No. DT/SAS-425/74 and tested in accordance with the program indicated in this report. It would be incorrect to extrapolate these results to conditions of use that deviate from the program forming the subject of this report.

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EVALUATION OF A NICKEL-HYDROGEN BATTERY FOR SPACE APPLICATION

FINAL REPORT

EVALUATION OF A NICKEL-HYDROGEN BATTERY FOR SPACE APPLICATION FINAL REPORT /4/ *

1. SPACE QUALIFICATION

1.1. Introduction

This report presents the results of the space qualification tests and of the characteristics shown by the HR 23S nickel-hydrogen battery.

Its objective is two-fold:

- to make possible a better understanding of the characteristics of the nickel-hydrogen battery
- to make an objective comparison with the nickel-cadmium battery

The following reference documents have been taken into consideration:

- technical clauses in the ESTEC contract, no. 2345/74/HP
- specification 340 126
- electrical and thermal characteristics of the Ni-Cd battery VO20S (new designation for VO23S) no. 59-71-DL/JM in the framework of ESTEC contract 877/69/HP
- manufacturing and test document no. DT/SAS-425/74

Test Program

The tests have been carried out in conformity with specification 340 126 for space qualification, partially modified. The modifications rest on the following points:

- 8 batteries instead of 15 undergo the qualification tests
- the mechanical tests and the charge preservation tests following mechanical tests are not carried out

During this qualification, the nickel-hydrogen battery HR 23S will be likened to a cylindrical battery (charge to Cs/5 during 7 hours according to specification 340 126).

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* Numbers in margin indicate foreign pagination

1.2 Specification 340 126

AEROSPACE SECTION

IV- CERTIFICATION TESTING

The certification testing consists of the following tests:

- tightness (electrolyte leakage, helium),
- standard output ($20^{o}C$),
- output at low temperature ($0^{o}C$),
- output at high temperature ($40^{o}C$),
- overload,
- charge preservation,
- mechanical tests (shock, vibration, acceleration),
- charge preservation
- internal resistance,
- standard output ($20^{o}C$),
- tightness.

4.1 Tightness Test

After cleaning of the cells, two types of tightness checks are carried out:

- maintenance of a short on the battery for a minimum of 16 hours, then elimination of the short prior to tightness tests,
- detection of leaks of the electrolyte using cresol red solution. No red coloration must appear,
- detection of leaks by sweating, or by internal helium. The leaks must be less than $F = 10^{-7} cm^3$ ATm/sec.

4.2 Test of Standard Output

The batteries are put through a charge and a discharge under the standard conditions defined in para II, i.e.:

- temperature: $20^{o}C$
- constant charge current $\frac{Cn}{5}$ amperes for 7 hours for cylindrical batteries and $\frac{Cn}{10}$ amperes for 15 hours for oblong-shaped batteries,
- off-line time: 1 hour minimum,
- constant discharge current $\frac{Cn}{5}$ amperes until the battery voltage attains 1.0 V.

The discharge determines the individual standard output Cs_{ind}. This output will be greater than the nominal capacity of the batteries.

$$Cs_{ind} \geqslant Cn$$

- after this test, the batteries are discharged through a resistance of 1 ± 0.1 ohms for 16 hours.
- place under short circuit for a minimum of two hours

4.3 Test of Low Temperature Output

The batteries are subjected to two charge-discharge cycles, defined as follows:

- temperature: 0^{o}
- constant charging current of $\frac{Cs}{5}$ for 7 hours for cylindrical batteries and $\frac{Cs}{10}$ amperes for 12 hours for oblong shaped batteries,
- off-line time: 1 hour minimum,
- constant discharge current of $\frac{Cs}{5}$ amperes until put on line battery voltage is 1.0 V.

The second discharge gives the individual low temperature output C_{BT}. One must have for each battery,

$$C_{BT} \geqslant 0.85\ Cs$$

(Cs is standard output for the battery lot)

- return batteries to ambient temperature in 2 hours minimum
- maintain short for two hours minimum,

4.4 High Temperature Output Test

The batteries are subjected to two cycles defined as follows:

- temperature: $40^{o}C$
- constant charging current of $\frac{Cs}{5}$ amperes for 8 hours,
- off-line time: 1 hour minimum,
- constant discharge current of $\frac{Cs}{5}$ until the battery voltage reaches 1.0 V.

The second discharge gives the individual high temperature output C_{HT}. One must have for each battery

$$C_{HT} \geqslant 0.55\ Cs$$

AEROSPACE SECTION

- return batteries to ambient temperature in 2 hours minimum,
- maintain short circuit of the batteries for 2 hours minimum.

4.5 Overload Test

The batteries undergo the following test:

- temperature: 20°C
- constant charging at $\frac{Cs}{5}$ amperes for 7 hours for the cylindrical batteries and $\frac{Cs}{10}$ for 15 hours for the oblong-shaped batteries,
- overcharge 48 hours in the respective ranges listed above.

In the course of this overcharging, the voltage of each battery has to be less than 1.495 V for cylindrical batteries and 1.480 V for the oblong-shaped batteries,

- off-line time: 1 hour minimum
- constant discharge current of $\frac{Cs}{5}$ until the battery voltage reaches 1.0 V.

The discharge will give the individual output after overload C_{surch}.

One must have for each accumulator:

$$C_{surch} \geq 0.95\ Cs$$

(Cs is standard output for the battery lot)

- maintain short on the batteries for two hours minimum.

4.6 Test for Charge Preservation

This test consists of two parts:

Sort-circuit Test

- temperature: 20°C
- constant charging current of $\frac{Cs}{10}$ amperes for 10 minutes $\pm$ 1%
- off-line time (open circuit): 48 hours minimum
- after this rest time, the voltage of each battery must be more than 1.170 V for cylindrical batteries and 1.180 V for oblong-shaped batteries.

Test for charge preservation:

The batteries undergo the cycle defined as follows:

- temperature: 20°C
- constant charging temperature $\frac{Cs}{5}$ amperes for 7 hours for cylindrical batteries and $\frac{Cs}{10}$ amperes for 15 hours for oblong-shaped batteries,

AEROSPACE SECTION

- off-line with open circuit for 192 hours (8 days) $\pm$ 1 hour,
- constant discharge current of $\frac{Cs}{5}$ amperes until the battery voltage reaches 1.0 V.

The discharge will give the individual output after storage C_{RC} . One must have for each battery:

$$C_{RC} \geqslant 0.80 \; Cs$$

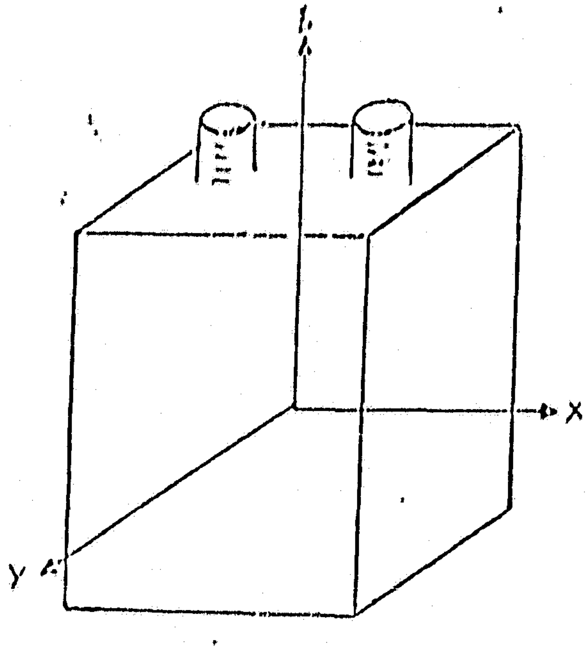
(Cs is standard output for the battery lot)

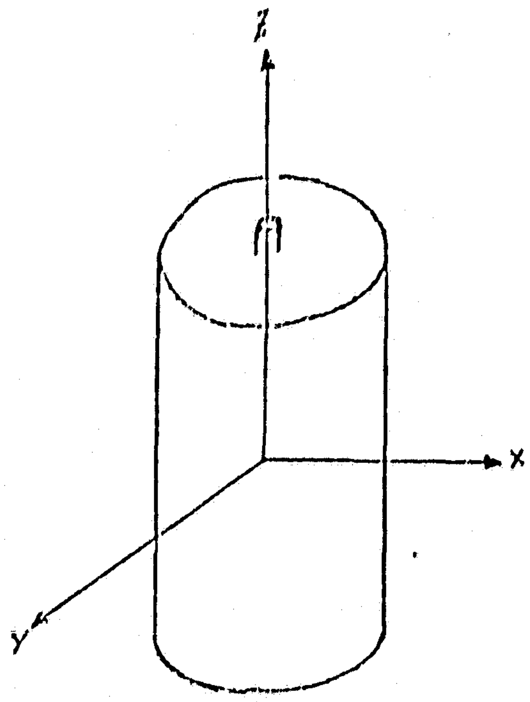
- maintain short circuit of the batteries for a minimum of 2 hours.

4.7 Mechanical Tests

The batteries undergo tests for shock, vibration and acceleration as defined below. During the tests the batteries are discharged and the voltage recorded. These three tests can be carried out in any order:

- charge before mechanical tests: same as para. 4.2
  - temperature: 20°C,
  - constant charging current $\frac{Cs}{5}$ amperes for 7 hours for the cylindrical batteries and $\frac{Cs}{10}$ amperes for 15 hours for oblong-shaped batteries.
- discharge during the mechanical tests:
  - temperature: 23°C $\pm$ 3°C,
  - discharge at $\frac{Cs}{10}$ $\pm$ 10% amperes at constant current or under resistance,
  - possible termination of the discharge if the battery voltage reaches 1.0 V. In this case a new charge must be carried out as indicated above,
  - recording of the current and voltage.





Z:	perpendicular to base of the box	Z :	perpendicular to base of the box
X:	perpendicular to the small side of the box	X:	two directions
			orthogonally parallel to
Y:	perpendicular to the large side of the box	Y.	the base of the box

AEROSPACE SECTION

- shock:
  - o shocks along three axes (X,Y,Z) for the oblong-shaped battery and along two axes (X,Z) for the cylindrical battery,
  - o one shock per axis
  - o characteristic :

    semi-sinusoidal form
    acceleration γ = 80g
    duration θ = 11 m sec
- vibration :
  - o vibration along 3 axes (X,Y,Z) for an oblong-shaped battery, along 2 axes (X,Z) for a cylindrical battery at the following levels:

	Axis	Frequency (Hz)	Level	Time
SINUS	Z	10-60	± 1.5mm (constant amplitude)	2 oct/min
		60-200	± 30 (g)	-
		200-500	± 20 (g)	-
		500-2000	± 5 (g)	-
	Y - X	10-30	± 1.2mm (constant amplitude)	-
		30-2000	± 10 (g)	-
WHITE NOISE	X-Y-Z	20-300	$0.003 g^2/Hz$ 6 db/oct	2 mn
		300-2000	$0.05\ g^2/$ Hertz	

- acceleration along the Z axis with a level of 40 g for 2mn.
- in the course of these tests variations of voltage are not acceptable other than those attributable to normal variation in voltage of a battery under discharge,
- after test, the batteries are placed in discharge at $\frac{Cs}{5}$ amperes until the voltage reaches 1.0 V,
- maintain short-circuit for 2 hours minimum.

4.8. Test for Charge Preservation after Short-Circuit

Same as short-circuit test in para. 4.6.

4.9. Internal Resistance Test

The internal resistance R of a battery breaks down into:

R_e = electrode resistance + electrolyte resistance

R_i = resistance at the electrode-electrolyte interface, constituting the resistance of polarization, electrochemical component of the internal resistance.

therefore, $R = R_e + R_i$

4.9.1 Measurement of R_e

Method : intensiostatic :

After an intensiostatic pulse I_o, the voltage variations are recorded; one observes:

1st time : a sudden slope (Δ U variation) contributed by R_e

2d time : a much gentler slope, contributed by R_i

Therefore: $R_e = \frac{\Delta U}{I_o}$

Operative mode :

Temperature: 20° C

Charge Status : battery charging at constant current of $\frac{Cs}{5}$ amperes for 7 hours for cylindrical batteries and $\frac{Cs}{10}$ amperes for 15 hours for oblong-shaped batteries.

Discharge at $\frac{Cs}{5}$ amperes for 2 hours

Measurement of the ohms of internal resistance is carried out from the voltage variations recorded in the course of the pulsed discharge at $\frac{Cs}{2} \pm 1\%$ ampere of a duration of 0.250 sec $\pm$ 1% spaced out at 0.750 sec $\pm$ 1%.

For each battery, the internal resistance must be:

$$R_e \leqslant \frac{40}{Cs} + 1.$$

4.9.2. Measurement of $R = R_e + R_i$

Temperature: $20^{\circ}C$

Charge Status: same as for 4.9.1

Operative mode:

- Measurement of voltage in open circuit U_co
- Discharge at $\frac{Cs}{2}$ during 10 secs.
- Measurement of the voltage U_{10}

$$R = \frac{U_co - U_{10}}{Cs/2}$$

The internal resistance must be:

$$R \leqslant \frac{100}{Cs}$$

AEROSPACE SECTION

4.10 Standard Output Test

- Temperature: 20°C
- constant charging current of $\frac{Cn}{5}$ amperes for 7 hours for cylindrical batteries and $\frac{Cn}{10}$ amperes for 15 hours for oblong-shaped batteries,
- off-line time: 1 hour minimum
- discharge at $\frac{Cn}{5}$ amperes until the battery voltage reaches 1.0 V.

The discharge gives the individual output. For each battery one must get:

$$C \geqslant 0.85\ Cs$$

(Cs is standard output of battery lot)

- maintain short-circuit for 2 hours minimum.

4.11 Leakage Test

same as in para. 4.1.

V- PRESENTATION OF RESULTS

The results of the certification testing are given in the format of the document attached herewith.

AEROSPACE SECTION

I - GENERAL DATA

Firm :
Address :
Country :
Battery type :
Cells :
Shape :
Nominal output :
Dimensions :
Weight :
Number of positive plates :
Number of negative plates :
Tank :
Manufacturing spec. :
Acceptance spec. :

II - RESULTS OF SPACE CERTIFICATION TESTS

Test	Specification	Measured Values	Certified
1) leakage a)			
b)			
2) standard output			
3) low temperature			
4) high temperature			
5) Overload			
6) Charge preservation a)			
b)			
7) Mechanical tests			
shock			
vibration			
acceleration			
8) Charge preservation			
9) Internal resistance a)			
b)			
10) Standard output			
11) Leakage a)			
b)			
CERTIFIED	YES - NO		

The type of battery defined above, having received 17 YES's is space certified.

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1.3. Qualification Tests

ANALYSIS OF RESULTS

1.3.1. Standard Output

The output obtained in actuality represents 115.2 % of the nominal output; Ni-Cd battery VO 18S in the same test achieved an actual output of 125.5% of rated output (table 1)

From the thermal point of view, VO 18S has a temperature at the end of charging of 21.2°C and reaches 20°C at the conclusion of discharge; the HR 23S has a temperature at the end of charging of 25°C and ends its discharge at 27°C.

Therefore, there is a difference in temperature at the conclusion of charging on the order of 4°C between the HR 23S and the VO 18S. The difference is much more significant at the end of discharge: 7°C. Therefore, one can foresee different behaviour between the two batteries, for example in low orbit cycling.

COMPARATIVE QUALIFICATION RESULTS ON Ni-Cd BATTERY VO 18S AND $Ni-H_2$ BATTERY HR 23S TABLE 1

		VO 18S Ni-Cd						HR 23S $Ni-H_2$					
	Criteria (340126)	U(V) end of charge	Output (AmpHr)	% Cs	R_e (mΩ)	R (mΩ)	Temp. end of charge	U(V) end of charge	Output (AmpHr)	% Cs	Re (mΩ)	R (mΩ)	Temp. end of charge
Standard output 20^oC	Cs ≥ Cn	1.433	22.60	100			21.2	1.520	26.50	100			25
Low temperature output: 0^oC	CBT ≥ 0.85xCs	1.525	23.59	104.4			3.3	1.448	28.52	107.6			17
High temperature output: 40^oC	CHT ≥ 0.55xCs	1.474	15.26	67.5			46	1.414	16.40	61.9			62.3
Overload test**	U_{surch} ≤ 1.495 ≥ 0.95 x Cs	end of over-charge 1.429	22.44	99.3			25.2	end of over-charge 1.453	29.96	113.1			41.5
Charge preservation test (short-circuit test)	$U_{open\ circuit}$ ≥ 1.17V	Open circuit 1.188						open circuit 1.385					
Charge preservation test	C_{RC} ≥ 0.80Cs		20.84	92.2					20.40	77			
Charge preservation test (short circuit) after mechanical tests	$U_{open\ circuit}$ ≥ 1.17V	1.199						*					
Charge preservation test	C_{RC} ≥ 0.80Cs		20.83	92.2				*					
Internal resistance test	R_e ≤ 10 mΩ R ≤ 15mΩ				3.0	4.2					3.7	4.6	
Standard output test	C ≥ 0.85 x Cs	1.446	22.56	100.3				1.530	26.08	98.4			

* Not carried out
** Battery no. 88 has not been included in the mean computations from the overload test

1.3.2. Low Temperature Output Test /19/

Table 2 submits evidence of good performance by the HR 23S battery in cold conditions with 107.62% of its actual output; it is better than the best Ni-Cd (VO 4S) which only kept 104.83% of its actual output.

The VO 18S proceeds from a temperature of 1°C at the beginning of charging to 3.3°C at the conclusion of charging, thence to 2.3°C at the conclusion of discharge.

The HR 23S goes from a temperature of 0°C at the beginning of charging to 17°C at the conclusion of charging and to 18° C on conclusion of discharge.

The increase in temperature of the HR 23S is, therefore, greater than that of the VO 18S both at the end of charging and at the end of discharging.

Battery no. 88 shows signs of leakage: initial low pressure in the second cycle, zero pressure after placing under resistance.

COMPARATIVE RESULTS OF OUTPUTS ...?... OF $Ni-H_2$ BATTERY HR 23S AND Ni-Cd BATTERIES
VO 4S, VO 7S, VO 10S, VO 18S, VO 20S, VR 6FS
FOR THE VARIOUS CERTIFICATIONS

TABLE 2

	Criteria (340126)	VO 4S	VO 7S	VO 10S	VO 18S	VO 20S*	VR 6FS	Ni-Cd Average	HR 23 S
Standard output Ahr	Cs ≥ Cn	5.06	8.76	12.51	22.60	23.96	6.60	-	26.50
Low temperature output (%Cs)	$C_{BT} \geq 0.85Cs$	104.83	101.30	98.30	104.4	94.5	95.5	99.81	107.62
High temperature output (%Cs)	$C_{HT} \geq 0.55Cs$	80.70	71.43	84.84	67.5	61.56	87.5	75.59	61.89
Overload test (%Cs)	$C_{surch} \geq 0.95Cs$	113.46	106.26	100.27	99.3	104.1	107	105.06	113.06
Charge preservation (%Cs)	$C_{cc} \geq 0.80\ Cs$	95	96.29	93.53	92.2	92.45	89.5	93.16	76.98
Standard output (% Cs)	$C \geq 0.85\ Cs$	92.05	90.81	97.91	100.3	93.3	108	97.06	98.42

* new designation V) 23S

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1.3.3. High Temperature Output Test /21/

The output given back by the HR 23S is in the same scale of magnitude as the Ni-Cd of equivalent capacity:

61.56% for the VO 23S

61.89% for the HR 23S

Table 2 makes it possible to discover a decrease in output given back at 40°C as a function of the nominal output for the Ni-Cd, with the exception, however of the VO 10S.

One can attribute these results to two parameters:

- the variability of the level of precharge from one type of battery to another
- the characteristic dimensions of each type of battery which can lead to different thermal dissipation

The VO 18S goes from a temperature at the start of charging of 41°C to a temperature of 46°C at the conclusion of charging, thence to a temperature of 43°C at the end of discharge; the HR 23S goes from a temperature of 40°C to a temperature of 62.33°C at the conclusion of charging and to 48°C at the end of discharge.

The increase in temperature between the onset of charging and the end of charging is, therefore, much larger for the HR 23S than for the VO 18S. It is the same for the discharge.

1.3.4. Overload Test /22/

Good overload behaviour of the HR 23S is observed, on the order of the best of the Ni-Cd's (VO 4S): 113.46% of Cs versus 113.06% of Cs for the HR 23S.

From the thermal point of view, the VO 18S goes from 21°C to 25.2°C during the charging, thence to 27.7% at the end of the overcharge; the HR 23S goes from 20°C to 41.5°C during the charge, then to 43.4° at the conclusion

of the overcharging.

So there is an increase in temperature of 23.4°C for the HR 23S against an increase of 6.7° for the VO 18S

Battery no. 88 underwent a leakage check which discovered a leak at the level of the terminal connector. After tightening up, it has passed its qualification tests.

1.3.5. Charge Preservation Test /23/

Test 1:

The open circuit voltage after 48 hrs of charge preservation is 1.262 V for the HR 23S and 1.188 V for the VO 18S, so that the difference is 74 mV.

Test 2:

The unfavorable charge preservation of the nickel-hydrogen battery is shown in this test.

The result obtained: 77% of Cs is below the 340 126 acceptance criterion: 80% of Cs applies to the Ni-Cd battery.

1.3.6 Internal Resistance Test /24/

The resistance of a purely electrical character is 3.04 mΩ for the VO 18S and 3.74 mΩ for the HR 23S, that is a 0.70 mΩ deviation, i.e. 23% more for the HR 23S than for the VO 18S.

The total resistance R is 4.24 mΩ for the VO 18S against 4.67 mΩ for the HR 23S, i.e. 10.1% more for the HR 23S than for the VO 18S.

1.3.7 Standard Output Test /25/

The value obtained of 98.42% of Cs at the beginning of qualification is very close to the Ni-Cd mean value of 97.06 (table 2).

If one does not count batteries no. 88 and 89 whose outputs deviated from the population: 23.4 AmpHrs and 24.99 AmpHrs respectively, one gets for the other batteries a mean output of 26.70 AmpHrs, which is near the output found at the start of the qualification of 26.50 AmpHrs.

1.4. Results of the Qualification Tests

SPACE CERTIFICATION OF HR 23S BATTERIES

Standard output test

Charge 7 hours at 4.60 A at +20°C
Off-line 1 hr-discharge at 4.60 A, +20°C until 1V

BATTERY N°	BEFORE CHARGE			END OF CHARGING			END OF DISCHARGE			AFTER PLACING UNDER R= 0.2 Ω	
	U VOLTS	P BARS	T °C	U	P	T	C AH	P	T	U	P
88	1,201	2,15	20	1,524	30,1	25	26,62	6,0	27	0	3,4
89	1,210	2,15	20	1,520	30,1	25	26,44	6,0	27	0,007	3,4
90	1,200	2,15	20	1,511	30,1	25	26,86	6,0	27	0,007	3,4
91	1,011	2,15	20	1,510	30,1	25	25,62	6,3	27	0	4,3
92	1,200	2,15	20	1,524	30,1	25	26,68	6,0	27	0	3,4
95	1,203	2,15	20	1,524	30,1	25	26,68	6,0	27	0	3,4
96	1,200	2,15	20	1,527	30,1	25	26,66	6,0	27	0,007	3,4
98	1,201	2,15	20	1,521	30,1	25	26,54	6,0	27	0,007	3,4

OUTPUT C_S 26,50 AH

SPACE CERTIFICATION OF HR23S BATTERIES

Low temperature output test-1st cycle — Charge 7 hrs @ 5.3A at $0^{o}C$-off-line 1 hr discharge @ 5.3A at $0^{o}C$ until 1V

BATTERY N°	BEFORE CHARGE			END OF CHARGING			END OF DISCHARGE			AFTER PLACING UNDER R= 0.2Ω	
	U VOLTS	P BARS	T C	U	P	T	C AH	P	T	U	P
88	0,540	3,4	0	1,541	29,4	-15	27,41	3,0	7,5		
89	0,534	3,4	0	1,540	30,0	-14	27,23	6,9	7		
90	0,534	3,4	0	1,552	31,0	-14	28,25	6,9	7		
91	0,514	4,3	0	1,561	32,7	-12	28,69	7,7	6		
92	0,480	3,4	0	1,550	30,0	-15	27,82	6,9	7		
95	0,442	3,4	0	1,554	30,0	-12	27,80	6,9	6		
96	0,537	3,4	0	1,553	30,0		27,72	6,9			
98	0,603	3,4	0	1,553	30,0		27,53	6,9			

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OUTPUT C_{BL} 27.86 AH

CYCLE 1

SPACE CERTIFICATION OF HR 23S BATTERIES

TEST N° 3
540 126

Low temperature output test-2d cycles

Charge 7 hrs @ 5.3A at $0^{\circ}C$- off-line 1 hr discharge @ 5.3A until 1V at $0^{\circ}C$

BATTERY N°	BEFORE CHARGE			END OF CHARGING			END OF DISCHARGE			AFTER PLACING UNDER R= 0.2Ω	
	U VOLTS	P BARS	T °C	U	P	T	C AH	P	T	U	P
88	1,282	2,9	0	1,548	32,7	18	28,10	2,1	8	0,010	0
89	1,291	6,9	0	1,541	35,4	17	31,95	6,9	8	0,006	2,6
90	1,290	6,9	0	1,546	32,7	17	28,21	6,9	8	0,006	2,6
91	1,295	8,2	0	1,551	35,3	16	29,41	7,7	8	0,006	3,5
92	1,281	6,9	0	1,541	32,7	15	28,51	6,9	8	0,005	2,6
95	1,290	6,9	0	1,550	32,7	14	28,50	6,9	8	0,005	2,6
96	1,290	6,9		1,550	32,7		29,46	6,9		0,005	2,6
98	1,291	6,9		1,550	32,7		28,20	6,9		0,007	2,6

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OUTPUT [illegible] 28,52 AH

SPACE CERTIFICATION OF HR 23S BATTERIES

TEST N° 4
340 126

High temperature
output test-1st cycle

Charge 8 hrs @ 5.3A at +40°C, off-line 1V
Discharge at 5.3A until 1 volt

BATTERY N°	BEFORE CHARGE			END OF CHARGING			END OF DISCHARGE			AFTER PLACING UNDER R= 0.2Ω	
	U VOLTS	P BARS	T °C	U	P	T	C AH	P	T	U	P
88	[illegible]	[illegible]	41	1,420	20,6	60	16,55	4,9	46		
89	1,093	3,4	41	1,415	29,0	60	18,40	8,6	46		
90	1,057	3,4	41	1,414	29,2	60	18,03	8,6	46		
91	[illegible]	3,4	41	1,420	33,7	52	20,02	11,2	46		
92	[illegible]	3,4	41	1,415	29,2	60	17,62	8,6	46		
95	1,052	3,4	41	1,421	29,0	56	18,24	8,6	46		
96	1,100	3,4		1,421	29,0		18,50	8,6			
98	[illegible]	3,4		1,418	29,[illegible]		18,64	[illegible]			

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OUTPUT [illegible] 18,25 AH

SPACE CERTIFICATION OF HR 23S BATTERIES

TEST N°4
340 126

High temperature
output test-2d cycle

Charge 8 hrs @ 5.3A at 40°C, off-line 1 hr
Discharge at 5.3A until 1 V at +40°C

BATTERY N°	BEFORE CHARGE			END OF CHARGING			END OF DISCHARGE			AFTER PLACING UNDER R= 0.2Ω	
	U VOLTS	P BARS	T °C	U	P	T	C AH	P	T	U	P
88	1,251	1,9	40	1,407	19,8	68	15,10	8,1	48	0,003	0
89	1,276	6,9	40	1,413	28,4	62	16,60	6,9	48	0,004	3,4
90	1,276	6,9	40	1,413	28,4	62	16,22	6,9	48	0,003	3,4
91	1,281	7.7	40	1,425	31,0	60	17.68	8.6	48	0,003	4,3
92	1,276	6.9	40	1,414	28,4	62	16,01	6,9	48	0,003	3,4
95	1,277	6,9	40	1,410	28,4	60	16,40	6,9	48	0,003	3,4
96	1,276	6,9		1,411	28,4		16,52	6,9		0,003	3,4
98	1,277	6.9		1,416	28,4		16,65	6,9		0,003	3,4

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OUTPUT CIHT 16,40 AH
cycle No 2

0,62 Cs

SPACE CERTIFICATION OF HR 23S BATTERIES

TEST N: 5
340126

Overload test — Charge 7 hrs at 5.3A at +20°C
Overcharge 48 hrs at 5.3A, off-line 1 hr
discharge at 5.3 A

N: BATTERY	BEFORE CHARGE			END OF CHARGING			END OF OVERCHARGE			END OF DISCHARGE			AFTER PLACING UNDER R= 0.2Ω	
	U	P	T	U	P	T	U	P	T	C AH	P	T	U	P
88	0,837	0	20	1,507	30,1	46	1,441	21,5	48	20,50	0		0,047	0
89	0,017	3,4	20	1,517	36,1	42	1,451	40,4	45	29,38	8,6		0,005	5,2
90	0,022	3,4	20	1,522	36,1	42	1,450	40,4	44	30,44	8,6	.....	0,006	5,2
91	0,031	4,3	20	1,531	37	39	1,460	44,3	44	31,02	9,5	.....	0,005	6,9
92	0,017	3,4	20	1,511	36,1	43	1,450	41,3	45	29,79	8,6	.....	0,005	5,2
95	0,022	3,4	20	1,522	36,1	37	1,460	42,1	40	29,70	8,6	.....	0,005	5,2
96	0,020	3,4	20	1,520	36,1		1,457	43	39	29,77	8,6		0,007	5,2
98	0,021	3,4	20	1,521	36,1		1,453	43	42	29,67	8,6	.....	0,007	5,2

OUTPUT 29,96 AH
OVERCHARGE

SPACE CERTIFICATION OF HR 23S BATTERIES

TEST N° 6

340.126

Charge preservation test   Test #1

Charge 10 min at 2.65 A +20°C
Off-line 48 hrs

BATTERY N°	BEFORE CHARGE			END OF DISCHARGE			AFTER 48 HRS OFF-LINE	
	U (V)	P (bars)		U	P		U	P
88	0,215	0		0,934	0			
89	0,205	5,2		1,381	5,2		1,262	5,2
90	0,207	5,2		1,380	5,2		1,261	5,2
91	0,177	6,9		1,395	6,9		1,268	6,9
92	0,216	5,2		1,380	5,2		1,260	5,2
95	0,221	5,2		1,387	5,2		1,260	5,2
96	0,230	5,2		1,381	5,2		1,261	5,2
98	0,230	5,2		1,390	5,2		1,261	5,2

SPACE CERTIFICATION OF HR 23S BATTERIES

TEST N° 6

340 126

Charge conservation test. Test #2

Charge 7 hrs at 5.3 A at +20°C
Off-line 8 days. discharge @ 5.3A until 1 V

BATTERY N°	BEFORE CHARGE.			END OF CHARGING			AFTER 8 DAYS OFF-LINE			END OF DISCHARGE			AFTER PLACING UNDER R= 0.2Ω	
	U	P	T	U	P	T	U	P	T	C (Ah)	P	T	U	P
88	1,228	0,9	20	1,528	21,5		1,343	19,70	20	19,40	3.01		0,008	0
89	1,263	5,2	20	1,523	35,3		1,342	25,8	20	20,31	8,6		0,007	5,2
90	1,262	5,2	20	1,526	35,3		1,343	26,7	20	20,84	8,6		0,006	5,2
91	1,269	6,9	20	1,532	37,8		1,347	28,8	20	21,04	10,3		0,007	6.9
92	1,262	5,2	20	1,523	35,3		1,342	25,8	20	20,41	8,6		0,006	5,2
95	1,262	5,2	20	1,524	35,3		1,343	25,8	20	20,41	8,6		0,006	5,2
96	1,262	5,2	20	1,522	35,3		1,342	25,8	20	20,41	8,6		0,006	5,2
98	1,262	5,2	20	1,526	35,3		1,341	25,8	20	20,41	8,6		0,008	5,2

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OUTPUT 20,40 Ah

CRC

SPACE CERTIFICATION OF HR 23S BATTERIES

TEST N°9

340 126

Test of internal resistance-measure R&R_e

Charge 7 hrs @ 5.3 amp at +20°C
Off-line 1 hr, discharge at 5.3 amp

BATTERY N°	BEFORE CHARGE			END OF CHARGING			DISCHARGE 10 SEC AT 13,20A $R = \frac{C_0 - C_{10}}{0.5/2}$			DISCHARGE 0.25 SEC AT 0.75 SEC INTERVALS $R_e = \frac{\Delta U}{\Delta I}$ 5eme Pointe			END OF DISCHARGE	
	U	P	T	U	P	T	C_0	C_{10}	R mΩ	ΔU mV	ΔI A	Re	C (Ah)	P
88	1.272	0		1.536	27.9		1,336	1,255	6,1	66	14,8	4,5	21,73	3,1
89	1.312	5,2		1,525	36,5		1,342	1,279	4,8	56	14.8	3.8	25,79	6,7
90	1.317	5,2		1,528	37.7		1,345	1,285	4,5	54	14,8	3,6	26,77	7,1
91	1,322	6.9		1,535	39,4		1,348	1,282	5	56	14,8	3,8	26,77	9.3
92	1,316	5.2		1,522	36,5		1,343	1,281	4,7	55	14,8	3,7	26,77	6,5
95	1,317	5.2		1,524	36.8		1,344	1,284	4,5	55	14,8	3,7	26,15	7,1
96	1,315	5.2		1,541	36.6		1,342	1,280	4,7	55	14,8	3,7	25,79	6,7
98	1,314	5.2		1,529	37.0		1,344	1,284	4,5	57	14,8	3,9	25.62	6,9

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SPACE CERTIFICATION OF HR 23S BATTERIES

TEST N° 10
340 126

Standard output test

Charge 7 hrs at 4.60 Amp at +20°C
Off-line 1 hr, discharge at 4.60 Amp at +20°C

BATTERY N°	BEFORE CHARGE			END OF CHARGING			END OF DISCHARGE			AFTER PLACING UNDER R= 0.2Ω	
	U VOLTS	P BARS	T °C	U	P	T	C AH	P	T	U	P
88	1,190	2.9		1,522	26,14		23,40	2,9		2	0,1
89	1,277	6,2		1,531	33.9		24,99	9,3		4	5,8
90	1,287	6,9		1,529	34,9		26,71	8,4		4	6.9
91	1,291	8,8		1,532	37.8		27.23	10,0		5	8,6
92	1,282	6.5		1,529	33,9		26.65	8,08		4	6.9
95	1,281	6.5		1,529	34,1		26,70	7,9		6	10,3
96	1,281	6,2		1,528	34,2		26,52	7,9		6	10,3
98	1,280	6,4		1,533	34,4		26,41	8,3		5	8.6

OUTPUT C_S 26,08 AH

2. ELECTRICAL AND THERMAL CHARACTERISTICS

2.1 General

The analysis of the electrical and thermal parameters of the HR 23S nickel-hydrogen battery is carried out as a function of the following four parameters:

- discharge temperature (θ)
- discharge intensity (I_D)
- charge intensity (I_C)
- charging coefficient (k)

8 batteries are tested, divided into two groups of 4 each. One group is used to carry out the tests C = f (k then θ), the second group for C = f (i_{ch} then i_{disch}).

The actual output Cs of the group will be defined as being the mean output of the qualification lot in the final cycle of specification 340 126, i.e. 26 amp hrs.

2.2. Definition of tests

The following tests have been carried out:

1. C = f (θ)

- temperature: 20 ± 1°C
- charge: Cs/10 = 2.6 A with k = 1.2
- discharge: Cs/5 = 5.2 A until 1 volt/ battery at the following temperatures: 20, 0, 20 and 40°C (tolerance ± 1°C).

2. C = f (kθ)

- temperature : 20 ± 1°C
- charge : Cs/10 = 2.6 A with kθ = 1.2, 1.3, 1.4, and 1.5.
- off-line time 1 hr
- discharge: Cs/5 = 5.2 A until 1 V/ battery at 20°C ± 1°

3. C = f (i_c) /38/

- temperature: 20 ± 1°C
- charging in the following regimes:

  Cs/30 = 0.870 A

  Cs/20 = 1.3 A

  Cs/10 = 2.6 A

  Cs/5 = 5.2 A

  Cs/3 = 8.70 A

  with k θ = 1.2

- off-line: 1 hour
- discharge: Cs/5 = 5.2 A until 1 volt/battery at temperature of 20 ± 1°C.

4. $C = f\ (i_d)$
   - temperature : 20 ± 1°C
   - charge: Cs/10 = 2.6 A with k = 1.2
   - off-line 1 hour
   - discharge in the following regimes:

     Cs/20 = 1.3 A

     Cs/10 = 2.6 A

     Cs/5 = 5.2 A

     Cs = 26 A

     2Cs = 52 A

     until 1 V/ battery at temperature 20° ± 1°C

5. Inversion Test
   - temperature: 20 ± 1°C
   - discharge: Cs/10 = 2.6 A

     Cs/5 = 5.2 A

     until pressure, voltage and temperature are stabilized.

6. Charge Preservation
   - temperature: 20 ± 1°C
   - charge : Cs/10 = 2.6 A
   - duration: 15 hours
   - off-line in open circuit: 8 days, temperature: 40°C, -20°C
   - discharge: Cs/5 = 5.2 A until 1 volt/battery at temperature /39/
     of 20 ± 1°C.

2.3 Electrical and Thermal Characteristics

2.3.1. $C = (f\ (i_c)$

2.3.1.1. Voltages

Voltages on conclusion of charging

Figure 5 shows the evolution of the voltage at the conclusion of charging for the 5 regimes considered. Different gradations of voltage are observed according to the charge regimes used:

1.410 V for Cs/30
1.415 V for Cs/20
1.430 V for Cs/10
1.442 V for Cs/5
1.470 for Cs/3

The different gradations can be explained by the voltage drops in the battery and in the connectors. We have determined experimentally that for a regime of 20 A one gets a voltage drop of 40 mV; the voltage drop in the battery is due to its internal resistance which we have estimated at 4.67 mΩ in the course of the qualification. To a first approximation we are able to compute the overall voltage drops:

/40/

Regime	Regime (A)	Δu connectors (mV)	Δu batteries (mV)	Δu total	Difference in voltage between 2 consecutive gradations (mV)	
					Computed value	Value read on the curve
Cs/30	0.87	1.74	4.06	5.80		
Cs/20	1.3	2.6	12.14	14.74	8.94	8
Cs/10	2.6	5.2	24.28	29.48	14.74	12
Cs/5	5.2	10.4	48.57	58.97	29.49	20
Cs/3	8.7	17.4	81.25	98.65	39.68	24

We can observe a significant difference between the calculated values and the values read on the curve for the Cs/3 and Cs/5 regimes. It would seem then that the internal resistance is a function of the intensity.

It is to be noted that the stronger the regime is, the less constant is the voltage gradation. At Cs/3 the curve is constantly growing.

We can ascertain that at the initial instant the voltage assumes two values:

1.30 V for Cs/30 and Cs/10
1.35 for Cs/5 and Cs/3

For the Cs/3, Cs/5 and Cs/10 regimes one observes a peak and then a decrease at the end of charging, the battery being completely charged, its voltage decreases slightly in overcharge.

One can thus deduce the fact that for the Cs/20 and Cs/30 regimes the battery is not completely charged.

Voltage on Conclusion of Discharge (figure 9) /41/

One does not see gradation differences in Figure 9, the voltage being constantly decreasing. Only the conclusion of discharge varies depending on the regimes considered, the stand-off of the voltage at the end of discharge taking place in the following order: Cs/3, Cs/5, Cs/10, Cs/20, Cs/30 which gives evidence of the increasing character if the curve $C = f\ (i_c)$.

2.3.1.2. Temperature (figure 8)

The fact is uncovered that for Cs/20 and Cs/30 the batteries are not completely charged, the overcharge is accompanied by an increase in temperature which is not observed for Cs/3, Cs/5, Cs/10.

During certification, while being charged witha charge coefficient of 1.4 (i.e.: 36.4 amp hrs), the temperature is 25°C. It is well verified that this point is on the Cs/10 curve.

2.3.1.3. Pressure (figures 6,7,10)

Figures 6,7,10 show us the purely linear character of the pressure.

During the off-line time of one hour a slight decrease in pressure sets in:
that is for Cs/20 and Cs/30 it is about 1.2 bar, for Cs/10 about 2.4 bar, CS/20 and Cs/30 (sic) about 2 bar. It is to be noted that the pressure on conclusion of discharge is equal to the initial pressure at the start of charging.

The end of discharge of a nickel-hydrogen battery can, therefore, be defined in voltage or pressure, for example, by a return to the initial pressure.

2.3.1.4. Output Restored (figure 1) /42/

Figure 1 confirms that for the Cs/30 and Cs/20 regimes the battery is not completely charged at the end of 12 hours. The best charge regime is Cs/3 (Cs/5 and Cs/10 being noticeable equivalents).

For a Cs/10 regime, the results obtained in the case of the characteristics

$C = f(i_d)$ and $C = f(k\theta)$ under identical test conditions are noticeably different:

$C = f(k\theta)$ approximately 99% of Cs

$C = f(i_d)$ approximately 100% of Cs

$C = f(i_c)$ approximately 101% of Cs

that is a difference of 2% between the extreme values. This behaviour can be explained by the incidence of previous testing and by the order in which the tests relating to the various regimes have been carried out; we are reproducing the "memory effect" of the Ni-Cd cell.

2.3.1.5. Comparison with the VO 20S

The curve of charging voltages is identical. The differences in gradation of the HR 23S nevertheless appear more marked than for the VO 20S (exception formed by Cs/3).

Only at Cs/30 for the VO 20S does one not observe maximum at the end of charging. The same effect can be observed on HR 23S at Cs/30 and Cs/20.

The thermal comparison with the VO 20S shows considerable deviations in /43/ temperature. Effectively, under identical test conditions one has for the VO 20S:

Regime	Temperature at end of charging
Cs/30	24.5
Cs/20	26.6
Cs/10	31
Cs/5	35.5
Cs/3	35

But it is not necessary to conclude that the VO 20S is more exothermic than the HR 23S at the end of the charging. The features of the VO 20S are that they have been made with metal plates enclosing 10 cells only separated by a sheet of PVC insulation 1mm thick; the cells in the middle heat up considerably therefore , and as a consequence heat up the neighboring cells.

Thus these results cannot be validly compared to those for the HR 23S.

The curve $C = f(i_c)$ of the VOS shows a maximum for Cs/10 contrary to the continuously increasing HR 23S.

Again one observes a "memory effect":

for $C = f(i_c)$ 98% Cs

for $C = f(i_d)$ 102% Cs

for $C = f(k\theta)$ 104% Cs

i.e. 6% of Cs between the extreme values.

2.3.2. $C = f(i_d)$ /44/

2.3.2.1. Voltage at End of Discharge (figure 11)

We observe curves of the same shape but shifted. We carry out the computations as in para 2.3.1.1.

Regime	Regime (A)	Δu connectors (mV)	Δu batteries (mV)	Δu total	Difference in voltage between 2 consecutive gradations (mV)	
					Computed value	Value read on the curve
Cs/20	1.3	2.6	6.07	8.67		
Cs/10	2.6	5.2	12.14	17.36	8.69	8
Cs/5	5.2	10.4	24.28	34.68	17.32	20
Cs	26	52	121.42	173.42	138.74	112
2Cs	50	100	233.5	333.5	160.08	148

The order of magnitude is verified. We can, at first approximation, conclude that at a shift of about Δu, due to the voltage drops, the voltage curve at the end of discharge is the same for all the regimes under consideration.

It is noted that all the curves increase during the entire duration of the discharge.

The measured voltage U is then in fact:

$$U = E - \sim I$$

the sum of the electromotive force of the battery and its voltage drop.

For halting the battery discharge one must then work with $U = 1 - \sim I$, instead of with 1 volt.

In the case of discharging at 2Cs, one gets $U = 1 - 0.16 = 0.84$ V.

Figure 17 shows us that for 0.84V, the restored output is: 25 amp hrs- i.e. 96% of Cs.

2.3.2.2. Temperature: figures 13,14,17 /45/

Figures 13 and 14 show us a linear variation of the temperature at the end of discharge. Point 2 Cs being excluded because it is not strictly speaking arrived at until the the end of its discharge, this explains the relatively low temperature.

After a 15 hour charge at Cs/10, discharge to 0.5 volts at 50 amperes was carried out with three thermocouples arranged as in figure 17.

Inspection of figure 17 shows an important thermal gradient at the conclusion of discharge.

Temperature B increases very rapidly, the battery terminals heat up very rapidly; temperatures C and A have very large thermal inertia, temperature C grows very rapidly afterwards, while B and A tend to stabilize at an equilibrium temperature.

Therefore, at the end of discharge, there will be a 10°C difference between the center and the edges of the battery. This gives evidence of the gradient of thermal dissipation in the HR 23S battery.

The result of the first discharge at 2Cs is confirmed by figure 8: after 13 amp hrs of discharge one gets a temperature of 31°C.

2.3.2.3. Pressures: figure 15

Figure 15 shows that the evolution of the pressure is hardly dependent on the discharge regime, an exception existing in the case of very intense regimes (2 Cs).

Figures 15 and 10 are identical at a pressure near ΔP. By ignoring this ΔP, one can plot a mean curve (figure 18).

For a given pressure, curve 18 shows us the status of the charge during the discharge of an HR 23S battery whatever has been its charge regime and whatever its discharge (at a temperature of 20°C with an error of about 2 amp hrs, i.e. 7.7%.

2.3.2.4. Restored Output (figure 16) /46/

Figure 17 shows us that the curve $C = f\ (i_d)$ is decreasing, this being essentially due to voltage drops in the connectors and in the battery (see figure 11).

2.3.2.5. Comparison with the VO 20S

The voltage curves at end of charging have the same shape for VO 20S as for the HR 23S.

The voltage drops are better in the case of HR 23S. The initial voltage of VO 20S varies between 1.24 and 1.35 V, that is 110 mV of variation compared to 1.15 V and 1.44 V, i.e. 290 mV for the HR 23S.

From the thermal point of view, one observes for the VO 20 S a decrease of its temperature for Cs/20, Cs/10 and Cs/5. During the discharge, it continues to dissipate the calories acquired during the charging, thence in the course of the discharge up until return to ambient temperature. It subsequently reheats at the end of the discharge; this can be explained by the poor thermal dissipation of the mounting which forms a compact mass and cools off very slowly.
For the HR 23S, the temperature is constant at Cs/10 and Cs/20, slightly increasing at Cs/5.
For a discharge regime of Cs, the VO 20S increases up to the following temperatures: 37°C at the end of the plate and 44°C at the center of the plate compared to 27°C for the HR 23S.
These temperatures are hard to compare. The VO 20S batteries at the center of the plate dissipate their calories by heating up their extremities. This consideration makes clear that the deviations in temperature between center and extremity would not be important.
For 2 Cs, the plate centers of the batteries are at a temperature of 52° C for 46° at the extremities, against 42°C for a discharge down to 0.5 V for the HR 23S.
The curves $C = f(i_d)$ are decreasing for the HR 23S and the VO 20S.
For 2 Cs, the VO 20S recovers 85% of its output against 50% for the HR 23S, this being explained by the significance of the voltage drops (see para 2.3.2.1.).

2.3.2. $C = f(\theta)$ /47/

2.3.3.1. Voltage at the end of discharge (figure 19)

Figure 19 shows us that the voltages at the end of discharge at different temperatures are decreasing. At 50% of the discharge depth, the voltages are the following:

40°C	1.290 V
20°C	1.276 V
0°C	1.280 V
-20°C	1.215 V

There is slight difference between the course of the curves between 0 and 40°C.

At $-20^{o}C$, the voltage shows smaller values on account of the increase in resistance within the battery.

2.3.3.2. Temperature (figure 20)

At Cs/10, the temperature varies little during dischargeing no matter what the exterior temperature: $0^{o}C$ at $20^{o}C$ and $40^{o}C$, $1^{o}C$ at $0^{o}C$ and $2^{o}C$ at $-20^{o}C$..

2.3.3.3. Pressure (figure 21)

Figure 21 shows us that the pressure slope increases with temperature. . c $20^{o}C$, the pressure curve coincides with the lower limit of figure 18 and therefore remains in this range.

One can also note in figure 22 that the pressure at the start of discharge is increasing with temperature.

2.3.3.4. Restored Output (figure 22) /48/

Figure 23 shows a maximum for $0^{o}C$; the optimum discharge temperature is thus $0^{o}C$.

The lost in restored output between $40^{o}C$ and $0^{o}C$ is : 9K of Cs.

It is noted that the restored energy which is represented by the surface situated underneath the discharge voltage curve (figure 19) is maximum for $0^{o}C$ and $20^{o}C$ and decreases at $40^{o}C$, then at $-20^{o}C$.

2.3.3.5. Comparison with VO 20S

VO 20S does not show a difference on the discharge curves between $0^{o}C$ and $40^{o}C$, 10 mV at 50% of discharge depth, i.e. the same value as for the HR 23S.

On the other hand at $-20^{o}C$ the difference is more marked for the HR 23S, 75 mV at 50% of discharge depth instead of the 20 mV for the VO 20S.

The initial voltage is increasing as a function of temperature for the HR 23S as well as for the VO 20S.

Looking at the thermals, one notes a more pronounced heating of the VO 20S, the temperature increase for the batteries at the extremeties of the plates being: $+2.5^{o}$ at $40^{o}C$, $+1.5^{o}$ at $20^{o}C$, $+2^{o}C$ at $0^{o}C$, $+2.5^{o}$ at $-20^{o}C$.

The optimum discharge temperature for the VO 20S lies between $15^{o}C$ and $25^{o}C$, the HR 23S shows an optimum discharge temperature between $-5^{o}C$ and $+10^{o}C$. The available outputs of the VO 20S vary between 90% and 96% of Cs against 91% and 100% of Cs for the HR 23S. The amplitude of the

variations in restored output in the range of temperatures considered is smaller for the the VO 20S than for the HR 23S, but on the contrary the optimum output is larger for the HR 23S than for the VO 20S.

2.3.4. $C = f\ (k\theta)$ /49/

2.3.4.1. Voltage (figure 23)

Voltage at End of Charging :
Figure 23 shows us that the charge coefficient is optimum for the values included between 1.3 and 1.4, maximum on the curve for the end of charging. The results contradict figure 5 in which, under the same test conditions the battery was completely charges with a coefficient of 1.2, this perhaps explained by the fact that $C = f(i_c)$ and $C = f\ (k\theta)$ have been carried out on two different groups of batteries and also by the difference in prior test- the "memory effect" of the batteries.

Voltage at End of Discharge (figure 24)

For k = 1.2, the battery is not completely charged; for k = 1.3, 1.4, or 1.5, the curves are confused. It is noted that the recovered energy is constant regardless of the coefficient of charge.

2.3.4.2. Temperature (figure 25)

The more the coefficient is increased, the more the temperature increases, the battery being overcharged.

2.3.4.3. Pressure (figure 26)

Figure 26 gives evidence that pressure stabilization begins for a coefficient between 1.3 and 1.4 for a charge duration between 13 and 14 hours. With a coefficient of 1.5, that is after 15 hours of charging, the pressure is stabilized.

The results of the qualification overload tests give evidence that for the Cs/5 regime the pressure at end of discharge has been stabilized at a higher level (36.1 bar at end of charging). The pressure stabilization at end of charging is thus a function of the charging regime. Moreover, it is determined that the start of pressure stabilization coincides with full battery charge.

2.3.4.4. Restored Output (figure 28) /50/

Figure 28 shows that for k = 1.3, 1.4, or 1.5, the battery is completely charged and for k = 1.2 it is not, whence a difference of 8% between the two values.

2.3.4.5. Comparison with the VO 20S

The course of the charging voltage is the same for the VO 20S and the HR 23S, nevertheless, the maximum of the end of charging is more accentuated and takes place at 105% of Cs instead of 134.6% of Cs for the HR 23S.

From the thermal point of view , the VO 20S heats up a great deal more: 37^{o}C at the end of charging for the extremities of the plates instead of 24^{o} for the HR 23S.

Just as previously it is difficult to draw a conclusion. In effect, the batteries heat up during overcharging and only dissipate very little. The VO 20S battery is not completely charged at k = 1.1 but it is for 1.2, 1.3, 1.4, and 1.5. The HR 23S is only completely charged from k = 1.3.

2.3.5 Preservation of Charge /51/

Figure 29 shows us the evolution of the available output after 8 hours off-line time as function of storage temperature. We have used the result of the certification storage to determine the +20^{o}C point. The curve considered is decreasing. We therefore saw that -20^{o}C is a better storage temperature than 20^{o}C or 40^{o}C. At 40^{o}C, 57% of output is lost in 8 hours compared with 3% only at -20^{o}C.

Figure 30 shows the loss in output as a function of the number of days. We find again the previous results: the loss is very rapid at 40^{o}C, 4% at the end of the first day, then 6.8% on the average on the other days. At -20^{o}C, the loss is very small- 2% on the first day, then 1% during the remaining 7 days.

At 20^{o}C the mean loss in output is 3.5% per day.

2.3.6 Inversion

The results (see tables) show that voltage stabilization takes place beginning in two hours, that the pressure stabilization is variable according to the batteries and the regimes, 3 hours at 5.2A and for nos. 95,98, and 90 at 2.6A and no. 89 and 91 at 1.3A and two hours for the others; the temperature is immediately stabilized.

2.4. Results on the Electrical and Thermal Characteristics

HR 23S BATTERIES
ELECTRICAL AND THERMAL CHARACTERISTICS

ORIGINAL PAGE IS
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CONTRAT E.S.T.E.C

N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

K01.5

PARAMETER STUDIED

$C = f(k_\theta)$

CHARGE 15 hours at 2.6 amp T = 20°C
OFF-LINE 1 hour at T = 20°C
DISCHARGE until 1.00 V at 5.2 amp T = 20°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
* 88	1.246	1.277	0	20	1.483	15.01	25	14.47	0	22
89	1.277	1.314	8.71	20	1.499	35,22	27	25.83	8.81	22
90	1.275	1.312	8.42	20	1.505	36.22	22	26.95	8.60	20
91	1.281	1.286	10.03	20	1.510	40.0	24	29.39	10.15	22

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.499	1.504	1.510
	PRESSURE	35.22	37.15	40.0
	TEMPERATURE	22	24.0	27
DISCHARGE	OUTPUT	25.83	27.39	29.39
	PRESSURE	8.60	9.20	10.15
	TEMPERATURE	20	21	22

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TABLEAU N°

HR 23 S BATTERIES ELECTRICAL AND THERMAL CHARACTERISTICS	CONTRAT E.S.T.E.C N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

PARAMETER STUDIED	$I_c = \frac{C_s}{30}$
$C = f(I_C)$	CHARGE 36 hours at 0.870 amp T = +20°C OFF-LINE 1 hour at T = + 20°C DISCHARGE until 1.00 V at 5.20 amp T = +20°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
92	1.300	1.319	7.10	19	1.480	31.20	19	25.65	7.88	19,5
95	1.298	1.317	7.14	19	1.476	31.68	19	25.65	8.06	20
96	1.298	1.318	7.03	19	1.476	31.20	19	25.65	7.86	19,5
98	1.302	1.325	7.58	19	1.477	31.80	19	25.22	8.58	20

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.476	1.477	1.480
	PRESSURE	31.20	31.46	31.80
	TEMPERATURE	19	19	19
DISCHARGE	OUTPUT	25.22	25.54	25.65
	PRESSURE	7.86	8.09	8.58
	TEMPERATURE	19.5	19.8	20

HR 23S BATTERIES
ELECTRICAL AND THERMAL CHARACTERISTICS

CONTRAT E.S.T.E.C
N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

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PARAMETER STUDIED

$C = f(I_C)$

I. $\frac{Cs}{20}$

CHARGE 24 hours at 1.3 amp T = 20°C
OFF-LINE 1 hour at T= 20°C
DISCHARGE to 1.00 V at 5.2 amp T = 20°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
92	1.302	1.321	7.69	20	1.491	32.08	20	25.91	8,07	20
95	1.301	1.319	7.74	20	1.490	32.73	20	26,00	8,24	20
96	1.307	1.322	7.58	20	1.491	32.26	20	26,00	8.07	20
98	1.305	1.327	8,24	20	1.489	32.99	21	25,39	8.84	21

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.489	1.490	1.491
	PRESSURE	32.08	32.51	32.99
	TEMPERATURE	20	20	21
DISCHARGE	OUTPUT	25,39	25.83	26,00
	PRESSURE	8.07	8.31	8.84
	TEMPERATURE	20	20	21

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TABLEAU N° 2

HR 23S BATTERIES
ELECTRICAL AND THERMAL CHARACTERISTICS

CONTRAT E.S.T.E.C
N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

PARAMETER STUDIED

$C = f(I_C)$

$I_C = \frac{C_e}{10}$

CHARGE 12 hours at 2.6 amp T = 20°C
OFF-LINE 1 hour at ________ T = 20°C
DISCHARGE to 1.00 V at 5.2 amp T= 20°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
92	1.294	1.326	7.26	19	1.518	32.85	19	26.52	7.79	19
95	1.292	1.327	7.40	19.5	1.516	33.38	20	26.52	8.05	20
96	1.293	1.330	7.14	19,5	1.516	32.97	20,5	26.52	7.77	20.5
98	1.295	1.339	7.96	20	1.515	33.93	22	25.82	8.72	21.5

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.515	1,516	1.518
	PRESSURE	32.85	33.28	33,93
	TEMPERATURE	19	20,5	22
DISCHARGE	OUTPUT	25.82	26.34	26.52
	PRESSURE	7.77	8.08	8.72
	TEMPERATURE	19	20	21.5

HR 23S BATTERIES
ELECTRICAL AND THERMAL CHARACTERISTICS

CONTRAT E.S.T.E.C
N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

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PARAMETER STUDIED

$C = f(I_C)$

$I_C = \frac{C_s}{5}$

CHARGE 6 hours at 5.2 amp T = 20°C
OFF-LINE 1 hour at T = 20°C
DISCHARGE to 1.00 V at 5.2 amp T = 20°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
92	1,296	1.359	7.59	19	1.537	33,99	20	26,61	8.10	19
95	1,295	1,358	8.01	19	1.535	34,43	23.5	26.61	8.29	21
96	1,294	1.366	7.49	19	1.536	34.00	20,5	26,52	8.12	20
98	1.299	1.368	8.37 7,87	19.5	1.532	35,23	24	25,91	8.77	21,5

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.532	1.535	1537
	PRESSURE	33.99	34.79	35,23
	TEMPERATURE	20	22	24
DISCHARGE	OUTPUT	25,91	26.41	26.61
	PRESSURE	8.10	8.32	8.77
	TEMPERATURE	19	20,4	21,5

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TABLEAU N° 1

HR 23S BATTERIES
ELECTRICAL AND THERMAL CHARACTERISTICS

CONTRAT E.S.T.E.C

N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

PARAMETER STUDIED

$C = f(I_C)$

$I_C = \frac{C_5}{3}$

CHARGE 3 hrs 35 min at 8.70 amp T = 20°C
OFF-LINE 1 hour at T = 20°C
DISCHARGE to 1.00 V at 5.2 am T = 20°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
92	1.291	1.386	7.50	19	1.559	33.76	20	26.86	8.10	19
95	1.289	1.386	7.50	19,5	1.558	34.19	24	26.95	8.27	21
96	1.290	1.393	7.58	19.5	1.559	33.88	21	26.95	8.08	20
98	1.291	1.403	8.00	20	1.553	34.83	26	26.35	8.82	21,5

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.553	1.557	1.559
	PRESSURE	33.76	34.17	34.83
	TEMPERATURE	20	23	26
DISCHARGE	OUTPUT	26.35	26.77	26.95
	PRESSURE	8.08	8.32	8.82
	TEMPERATURE	19	20.5	21.5

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TABLEAU N°
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HR 23S BATTERIES
ELECTRICAL AND THERMAL CHARACTERISTICS

CONTRAT E.S.T.E.C
N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

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PARAMETER STUDIED

$C = f\ (I_d)$

$I0 = \frac{C5}{20}$

CHARGE 12 hours at 2.6 amp T = 20°C
OFF-LINE 1 hour at T = 20°C
DISCHARGE to 1.00 V at 1.3 amp T = 20°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
92	1.289	1.324	7.43	20	1.512	33.02	20	27.20	7.33	20
95	1.288	1.323	7.52	20	1.512	33.56	21.5	27.21	7.52	20
96	1.287	1.327	7.22	20	1.512	33.09	20	27.13	7.36	20
98	1.289	1.333	7.91	20	1.510	34.07	22	26.84	7.86	20

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.510	1.511	1512
	PRESSURE	33.02	33.44	34.07
	TEMPERATURE	20	21	22
DISCHARGE	OUTPUT	26.84	27.09	27.21
	PRESSURE	7.33	7.52	7.86
	TEMPERATURE	/	20	/

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TABLEAU N° 6

High temperature output test 1st cycle

Charge 8 hrs @ 5.3 A at +40° Off-line 1 hr
Discharge at 5.3 amp to 1.0 V.

BATTERY NO.	BEFORE CHARGING			END OF CHARGING			DISCHARGE			AFTER PLACING UNDER R= 0.2 Ω	
	U VOLTS	P BARS	T °C	U	P	T	C AH	P	T	U	P
88	0,375	0	41	1,420	20,6	60	16,55	4,3	46		
89	1,093	3,4	41	1,415	29,5	60	18,40	5,6	46		
90	1,057	3,4	41	1,414	29,2	60	18,03	5,6	46		
91	0,612	3,4	41	1,420	33,7	59	20,02	11,2	46		
92	0,740	3,4	41	1,415	29,2	60	17,62	8,6	46		
95	1,050	3,4	41	1,421	29,0	58	18,24	5,6	46		
96	1,100	3,4		1,421	29,0		18,50	5,6			
98	1,105	3,4		1,410	29,2		18,64	5,6			

OUTPUT ITE [illegible] 18,25 AH

HR 23S BATTERIES
ELECTRICAL AND THERMAL CHARACTERISTICS

CONTRAT E.S.T.E.C
N° 2345/74/HP

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PARAMETER STUDIED

$C=f(I_D)$

$I.D. \frac{C_5}{5}$

CHARGE 12 hours at 2.6 amp T=20°C
OFF-LINE 1 hour at T=20°C
DISCHARGE to 1.00 V at 5.2 amp T=20°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
92	1.239	1.271	7.74	20	1.512	33.21	20	26.00	8.13	20
95	1.234	1.268	7.93	20	1.511	33.88	22	26.09	8.44	21
96	1.242	1.273	7.70	20	1.511	33.56	20	26.00	8.22	20
98	1.262	1.300	8.41	20	1.509	34.42	22	25.57	8.81	21.5

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.509	1.511	1.512
	PRESSURE	33.21	33.77	34.42
	TEMPERATURE	20	21	22
DISCHARGE	OUTPUT	25.57	25.92	26.09
	PRESSURE	8.13	8.40	8.81
	TEMPERATURE	20	20.5	21.5

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TABLEAU N° 8

HR 23S BATTERIES ELECTRICAL AND THERMAL CHARACTERISTICS	CONTRAT E.S.T.E.C N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

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PARAMETER STUDIED	$Id: \frac{C_5}{1}$
$C=f(Id)$	CHARGE 12 hours at 2.6 amp T = 20°C OFF-LINE 1 hour at T = 20°C DISCHARGE to 1.00 V at 2.6 amp T = 20°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
92	1.290	1.322	7.58	20	1.514	33.11	20	24.27	9.96	23
95	1.288	1.322	7.76	20	1.511	33.71	21	24.27	10.18	30
96	1.289	1.325	7.64	20	1.513	33.30	20	24.27	9.89	23.5
98	1.290	1.329	8.22	20	1.510	34.16	22	24.27	10.42	32

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.510	1.512	1.514
	PRESSURE	33.11	33.57	34.16
	TEMPERATURE	20	21	22
DISCHARGE	OUTPUT	—	24.27	—
	PRESSURE	9.89	10.11	10.42
	TEMPERATURE	23	27	32

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TABLEAU N° 9

HR 23S BATTERIES
ELECTRICAL AND THERMAL CHARACTERISTICS

CONTRAT E.S.T.E.C
N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

PARAMETER STUDIED

$C = f(I_d)$

Id = 2C5

CHARGE 12 hours at 2.6 amp T = 20°C
OFF-LINE 1 hour at T = 20°C
DISCHARGE to 1.00 V at 5.0 amp T = 20°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
92	1.318	1.338	9.89	20	1.507	33.97	20	13.30	18.92	22
95	1.317	1.339	10.03	20	1.504	34.95	22	13.30	19.78	30
* 96	1.317	1.339	9.80	20	1.506	34.52	20			
98	1.316	1.340	10.30	20	1.503	35.28	22	11.67	19.78	31

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.503	1.505	1.507
	PRESSURE	33.97	34.68	35.28
	TEMPERATURE	20	21	22
DISCHARGE	OUTPUT	11.67	12.76	13.30
	PRESSURE	19.78	19.49	18.92
	TEMPERATURE	22	27.5	31

HR 23S BATTERIES
ELECTRICAL AND THERMAL CHARACTERISTICS

CONTRAT E.S.T.E.C
N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

PARAMETER STUDIED

$C=f(\theta)$

$t = -20°C$

CHARGE 12 hours at 2.6 amp T = 20°C
OFF-LINE 24 hours at T = 20°C
DISCHARGE to 1.00 V at 5.2 amp T = 20°C

N°	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
BATTERY NO.	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
*88	1.282	1.331	3.13	20	1.517	27.07	20	10.00	3.83	-16
89	1.297	1.330	5.45	20	1.510	33.81	24	23.3	9.20	-16
90	1.296	1.329	8.27	20	1.516	34.35	20	24.1	8.86	-20
91	1.296	1.334	9.44	20	1.521	36.64	22	24.8	11.68	-19

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.510	1.516	1.521
	PRESSURE	33.81	34.93	36.64
	TEMPERATURE	20	22	24
DISCHARGE	OUTPUT	23.3	24.1	24.80
	PRESSURE	8.86	9.90	11.68
	TEMPERATURE	-16	-18	-20

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TABLEAU N° 11

HR 23S BATTERIES ELECTRICAL AND THERMAL CHARACTERISTICS	CONTRAT E.S.T.E.C N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

PARAMETER STUDIED	$t = 0°C$
$C = f(\theta)$	CHARGE 12 hours at 2.6 amp T = 20°C OFF-LINE 24 hours at T = 0°C DISCHARGE to 1.00 V at 5.2 amp T = 0°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
* 88	1.339	1.356	9.78	20	1.492	16.20	22	14.56	0.10	5
89	1.332	1.341	9.80	20	1.504	34.42	25	24.80	8.62	4
90	1.324	1.343	9.78	20	1.510	34.93	21	25.83	8.10	0
91	1.331	1.352	12.00	20	1.516	38.49	24	27.73	11.52	1

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.504	1.510	1.516
	PRESSURE	34.42	35.95	38.49
	TEMPERATURE	21	23	25
DISCHARGE	OUTPUT	24.80	26.12	27.73
	PRESSURE	8.10	9.41	11.52
	TEMPERATURE	0	1.5	4

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TABLEAU N° 12

HR 23S BATTERIES ELECTRICAL AND THERMAL CHARACTERISTICS	CONTRAT E.S.T.E.C N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

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PARAMETER STUDIED	t = 20°C
C=f (θ)	CHARGE 12 hours at 2.6 amp T= 20°C OFF-LINE 24 hours at T = 20°C DISCHARGE to 1.00 V at 5.21 amp T = 20°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
* 88	1.293	1.350	2.79	20	1.516	26.97	24	23,57	3.23	20
89	1.302	1.360	7.57	20	1.513	33.40	20	24,09	8.56	20
90	1.302	1.357	7.48	20	1.519	33.95	20	24.96	8.26	20
91	1.302	1.364	7.88	20	1.520	35.90	24	26.60	9.48	20

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.513	1.517	1.520
	PRESSURE	33.40	34.41	35.90
	TEMPERATURE	20	21	24
DISCHARGE	OUTPUT	24.09	25.22	26.60
	PRESSURE	8.26	8.77	9.48
	TEMPERATURE	20	20	20

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TABLEAU N° 13

HR 23S BATTERIES ELECTRICAL AND THERMAL CHARACTERISTICS	CONTRAT E.S.T.E.C N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

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PARAMETER STUDIED	t = 40°C	
$C = f(\theta)$	CHARGE 12 hours at 2.6 amp	T = 20°C
	OFF-LINE 24 hours at	T = 40°C
	DISCHARGE to 1.00 V at 5.2 amp	T = 40°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
* 88	1.291	1,311	0.172	20	1.489	15.44	24	12.13	0.10	40
89	1.300	1.325	9.27	20	1.506	34.36	21	22.44	8.89	40
90	1.299	1.325	8.82	20	1.512	34.90	20	23.40	8.56	40
91	1.299	1.329	10.34	20	1.518	37.46	25	24.87	9.99	40

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.506	1.512	1.518
	PRESSURE	34.36	35.57	37.46
	TEMPERATURE	20	22	25
DISCHARGE	OUTPUT	22.44	23.57	24.87
	PRESSURE	8.56	9.15	9.99
	TEMPERATURE	40	40	40

HR 23 S BATTERIES ELECTRICAL AND THERMAL CHARACTERISTICS	CONTRAT E.S.T.E.C N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

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PARAMETER STUDIED	$k_\theta = 1.2$
$C = f(K_\theta)$	CHARGE 12 hours at 2.6 amp T = 20°C 20 °C OFF-LINE 1 hour at T = 20°C 20 °C DISCHARGE to 1.00 V at 5.2 amp T = 20°C 20 °C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
* 88	981	1021	0	20	1.482	14.64	26	14.04	1.06	22
89	1.298	1.338	7.79	20	1.512	32.04	20	25.22	8.68	22
90	1.286	1.344	7.38	20	1.500	31.80	20	25.65	8.41	20
91	1.289	1.343	8.96	20	1.493	34.11	22	26.26	10.28	22

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.493	1.501	1.512
	PRESSURE	31.80	32.65	34.11
	TEMPERATURE	20	21	22
DISCHARGE	OUTPUT	25.22	25.71	26.26
	PRESSURE	8.41	9.10	10.28
	TEMPERATURE	20	21.5	22

HR 23S BATTERIES
ELECTRICAL AND THERMAL CHARACTERISTICS

CONTRAT E.S.T.E.C
N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

PARAMETER STUDIED

$C = f(K_\theta)$

k0, 1.3

CHARGE 13 hours at 2.6 amp T = 20°C
OFF-LINE 1 hour at T = 20°C
DISCHARGE to 1.00 V at 5.2 amp T = 20°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
* 88	1.242	1.288	0	20	1.483	14.98	25	14.70	0.06	22
89	1.288	1.328	8.58	20	1.502	34.79	26	25.74	8.75	22
90	1.288	1.328	8.34	20	1.509	35.62	21	26.87	8.48	20
91	1.288	1.330	9.91	20	1.515	39.00	24	29.03	10.04	22

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.502	1.508	1.515
	PRESSURE	34,79	36.47	39.00
	TEMPERATURE	21	24	26
DISCHARGE	OUTPUT	25.74	27.21	29.03
	PRESSURE	8.48	9.09	10.04
	TEMPERATURE	20	21	22

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TABLEAU N° 16

HR 23S BATTERIES
ELECTRICAL AND THERMAL CHARACTERISTICS

CONTRAT E.S.T.E.C
N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

PARAMETER STUDIED

$C = f(K_\theta)$

$K_\theta = 1.4$

CHARGE 14 hours at 2.6 amp		T = 20°C
OFF-LINE 1 hour at		T = 20°C
DISCHARGE to 1.00 V at 5.2 amp		T = 20°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
*88	943	980	0	20	1483	14.96	25	14.30	0.2	22
89	1,286	1,321	8,67	20	1,500	34.97	26	25.74	8.77	22
90	1.286	1324	8.39	20	1.506	35,93	21	26.78	8.74	20
91	1.283	1.323	9.96	20	1.512	39.59	24	29.03	10.28	22

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.500	1.506	1.512
	PRESSURE	34.97	36.83	39.59
	TEMPERATURE	21	24	26
DISCHARGE	OUTPUT	25.74	27.18	29.03
	PRESSURE	8.74	9.63	10.28
	TEMPERATURE	20	21	20

HR 23S BATTERIES ELECTRICAL AND THERMAL CHARACTERISTICS	CONTRAT E.S.T.E.C N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

PARAMETER STUDIED	Repos -20°c
C=f(c.ch$_\theta$)	CHARGE 15 hours at 2.6 amp T = 20°C OFF-LINE 8 days at T = -20°C DISCHARGE to 1.00 V at 5.2 amp T = -20°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
* 88	0.276	0.506	0	20	1.602	11.44	25	0	7.93	
89	0	0.131	5.62	20	1.510	35.36	21	24.10	9.15	
90	0	0.162	5.54	20	1.514	36.22	26	25.57	8.51	
91	0	0.126	7.05	20	1.520	39.73	24	26.00	8.74	

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.510	1.515	1.520
	PRESSURE	35.36	37.10	39.73
	TEMPERATURE	21	24.	26
DISCHARGE	OUTPUT	24.10	25.22	26.00
	PRESSURE	8.51	8.94	9.15
	TEMPERATURE			

HR 23 S BATTERIES ELECTRICAL AND THERMAL CHARACTERISTICS	CONTRAT E.S.T.E.C N° 2345/74/HP

SPECIFICATION/ECD/2/SPEC 21

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PARAMETER STUDIED	Repos +40°C
$C=f(c.ch_{\theta})$	CHARGE 15 hours at 2.6 amp T = 20°C OFF-LINE 8 days at T = 40°C DISCHARGE to 1.00 V at 5.21 amp T = 40°C

BATTERY NO.	BEFORE CHARGING				END OF CHARGING			DISCHARGE		
	C.O (V)	O (V)	P (bars)	T °C	F.C (V)	P (bars)	T °C	C (Ah)	P (bars)	T °C
92	0	0.179	4.33	20	1.518	34.78	20	12.04	8.79	
95	0	0.180	4.44	20	1.515	35.79	22	12.30	8.91	
96	0	0.226	4.75	20	1.517	35.16	20	12.04	8.74	
98	0	0.212	4.97	20	1.512	35.95	22	11.70	9.08	

		MINI	MEAN	MAXI
END OF CHARGING	VOLTAGE	1.512	1.516	1.518
	PRESSURE	34.78	35.42	35.95
	TEMPERATURE	20	21	22
DISCHARGE	OUTPUT	11.70	12.02	12.30
	PRESSURE	8.74	8.88	9.08
	TEMPERATURE			

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TABLEAU N° 19

HR 23S BATTERIES
ELECTRICAL AND THERMAL CHARACTERISTICS

CONTRAT E.S.T.E.C
N° 2345/74/HP

BATTERY NO.	Beginning of inversion			After 1 hour			after 2 hours			after 3 hours				
Inversion at 2.6 A until voltage, pressure and temperature stabilization														
	U	P	T	U	P	T	U	P	T	U	P	T		
92	-0,059	4.44	20	-0.068	4.45	20	-0.069	4.35	20	-0.069	4.37	20		
95	-0.057	4.61	20	-0,066	4.57	20	-0.067	4.56	20	-0.067	4.51	20		
96	-0,065	4.87	20	-0.068	4.88	20	-0.068	4.87	20	-0.069	4.88	20		
98	-0,064	5.09	20	-0.065	5.09	20	-0.066	5.09	20	-0,066	5.06	20		
Inversion at 5.2 A until voltage, pressure and temperature stabilization														
92	-0,102	4.33		-0,108	4.30		-0,110	4.33		-0,111	4.33			
95	-0,100	4.54		-0,105	4.47		-0,106	4.47		-0,107	4.44			
96	-0,102	4.83		-0,107	4.82		-0,108	4.80		-0,109	4.75			
98	-0,099	5.02		-0,104	4.97		-0,105	5.02		-0,106	4.97			

HR 23S BATTERIES
ELECTRICAL AND THERMAL CHARACTERISTICS

CONTRAT ESTEC

N°2345/74/HP

Inversion at 1.3 amp until voltage , pressure and temperature stabilization Pression . Temperature

BATTERY NO.	Beginning of inversion			After 1 hour			after 2 hours			after 3 hours				
	U	P	T	U	P	T	U	P	T	U	P	T		
89	-0,037	5.97	20	-0,039	5.92	20	-0,039	5.88	20	0,040	5.86	20		
90	-0,041	5.76	20	-0,040	5.73	20	-0,040	5.68	20	0,041	5.68	20		
91	-0,039	7.34	20	-0,038	7.22	20	-0,032	7.21	20	0,038	7.19	20		

Inversion at 2.6 A until voltage, pressure and temperature stabilization

89	-0,067	5.73	20	-0,062	5.76	20	-0,063	5.62	20	-0,063	5.62	20		
90	-0,068	5.62	20	-0.063	5.59	20	-0,064	5.55	20	-0,064	5.54	20		
91	-0,062	7.10	20	-0,059	7.12	20	-0,059	7.03	20	-0,060	7.05	20		

2.5. Curves

HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS

Fig. 1

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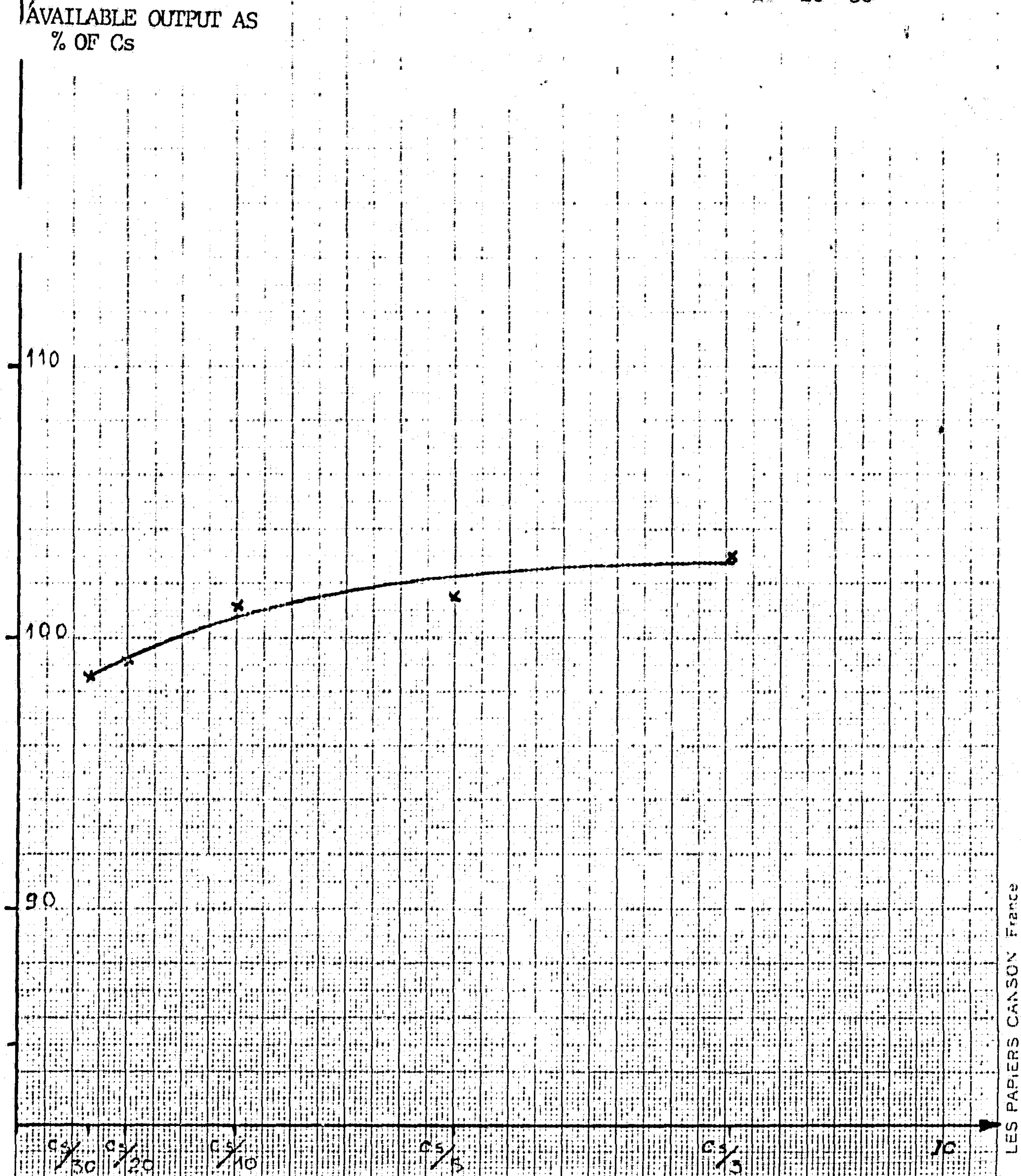
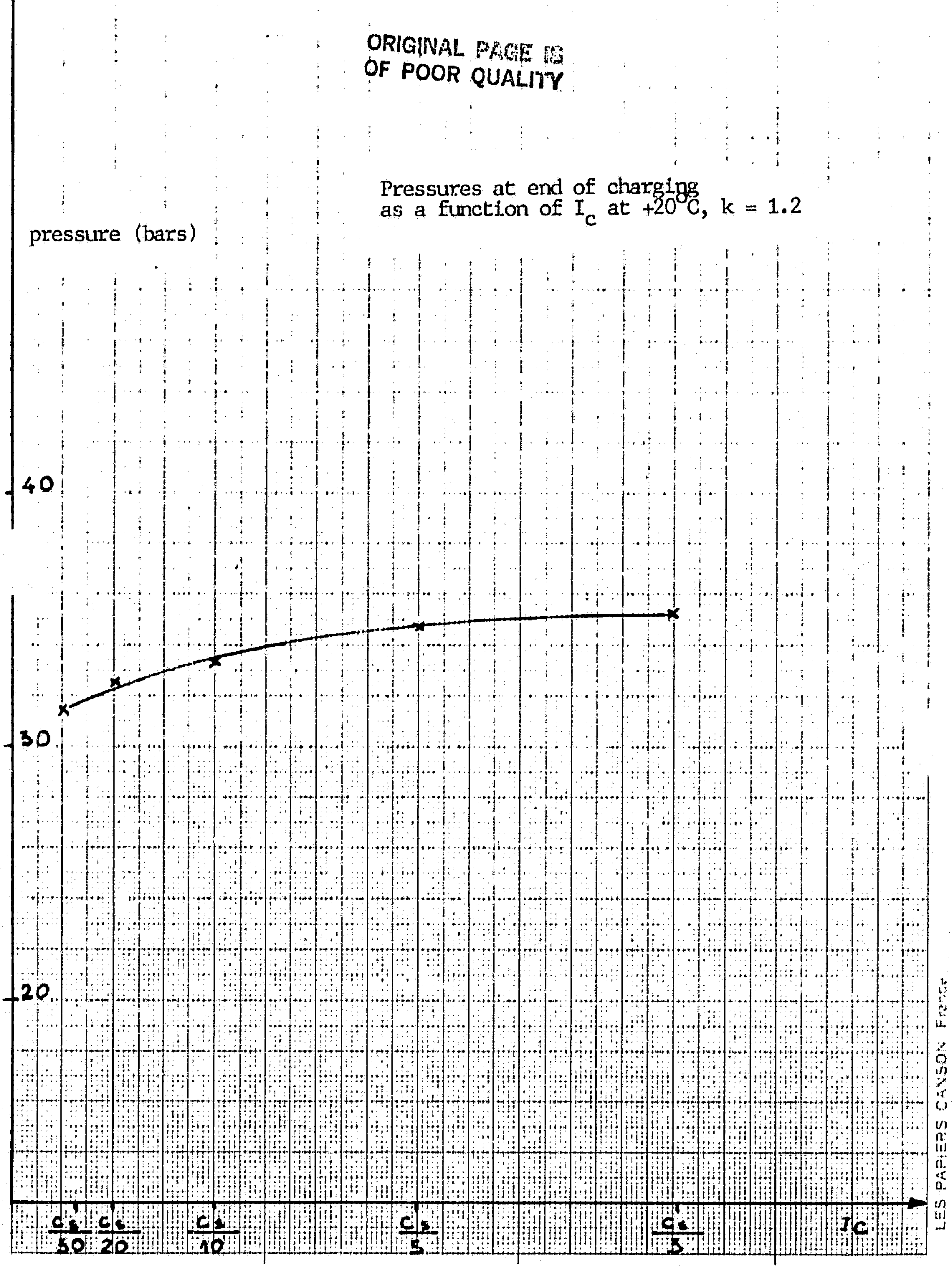
Available capacity + 20°C in discharge at Cs/5 as a function of I_c
After 12 hours charging at $\frac{Cs}{3}$, $\frac{Cs}{5}$, $\frac{Cs}{10}$, $\frac{Cs}{20}$, $\frac{Cs}{30}$



HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS

Fig. 2



HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS

Fig 3

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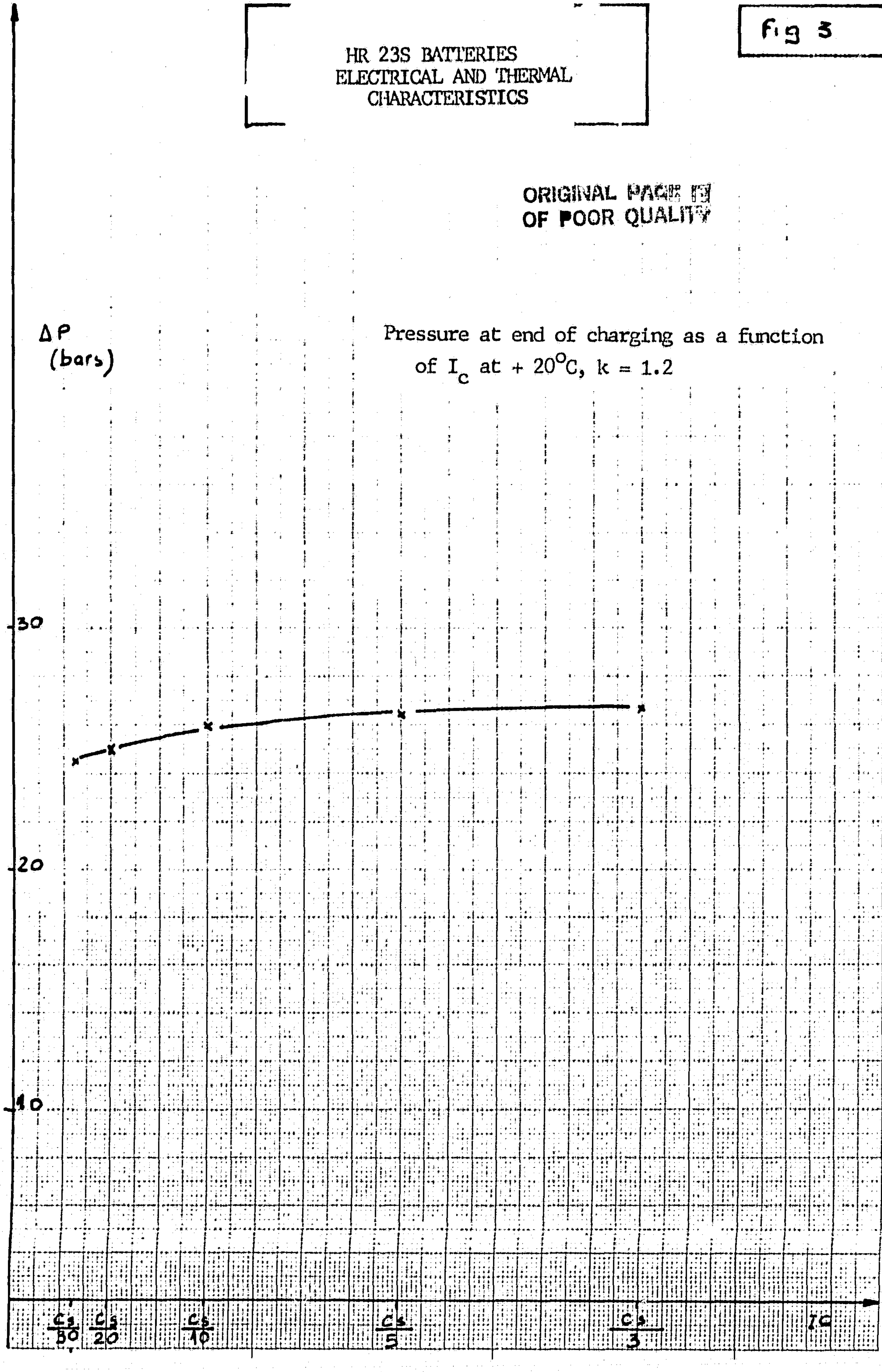

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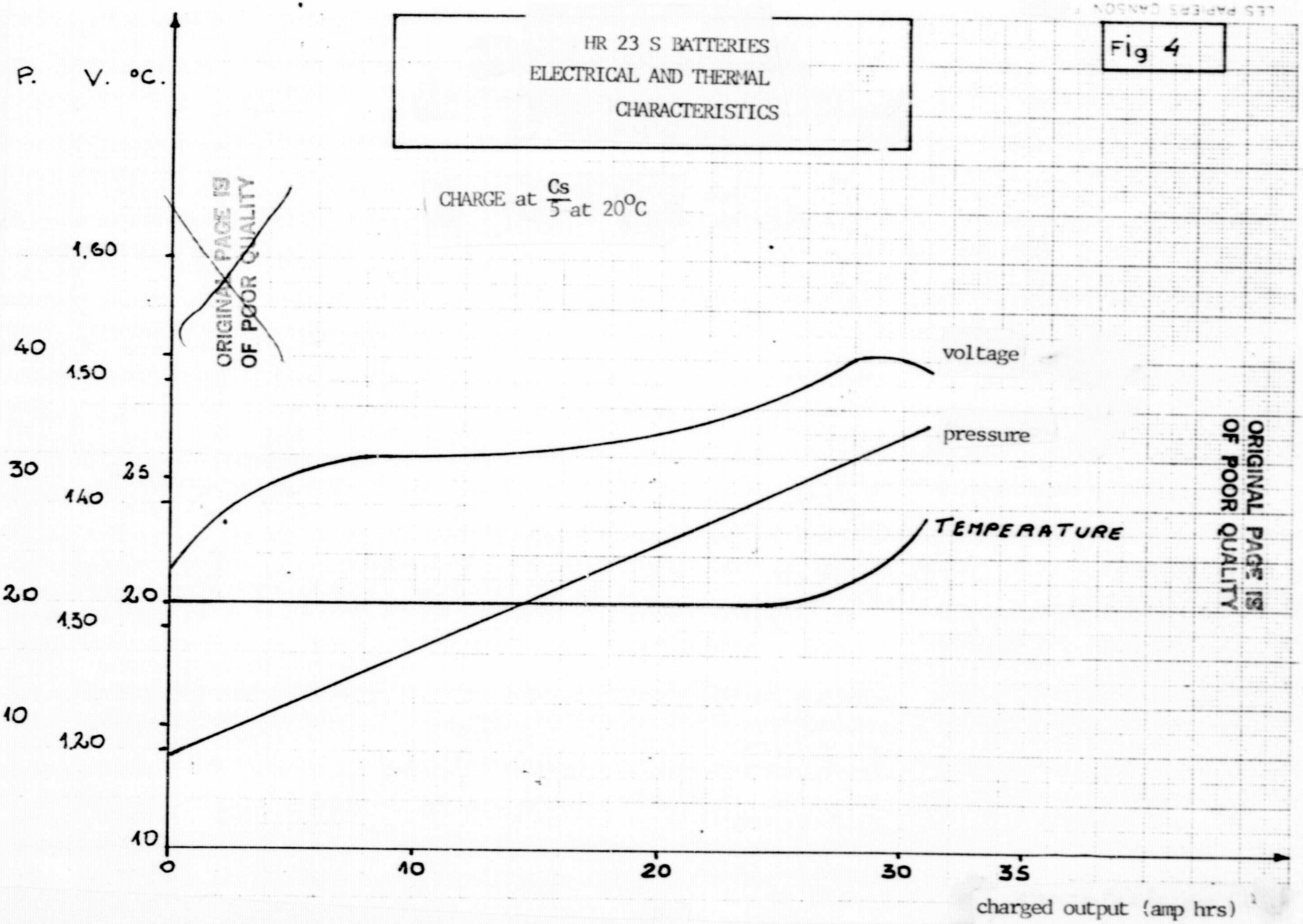
Fig 4

HR 23 S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS



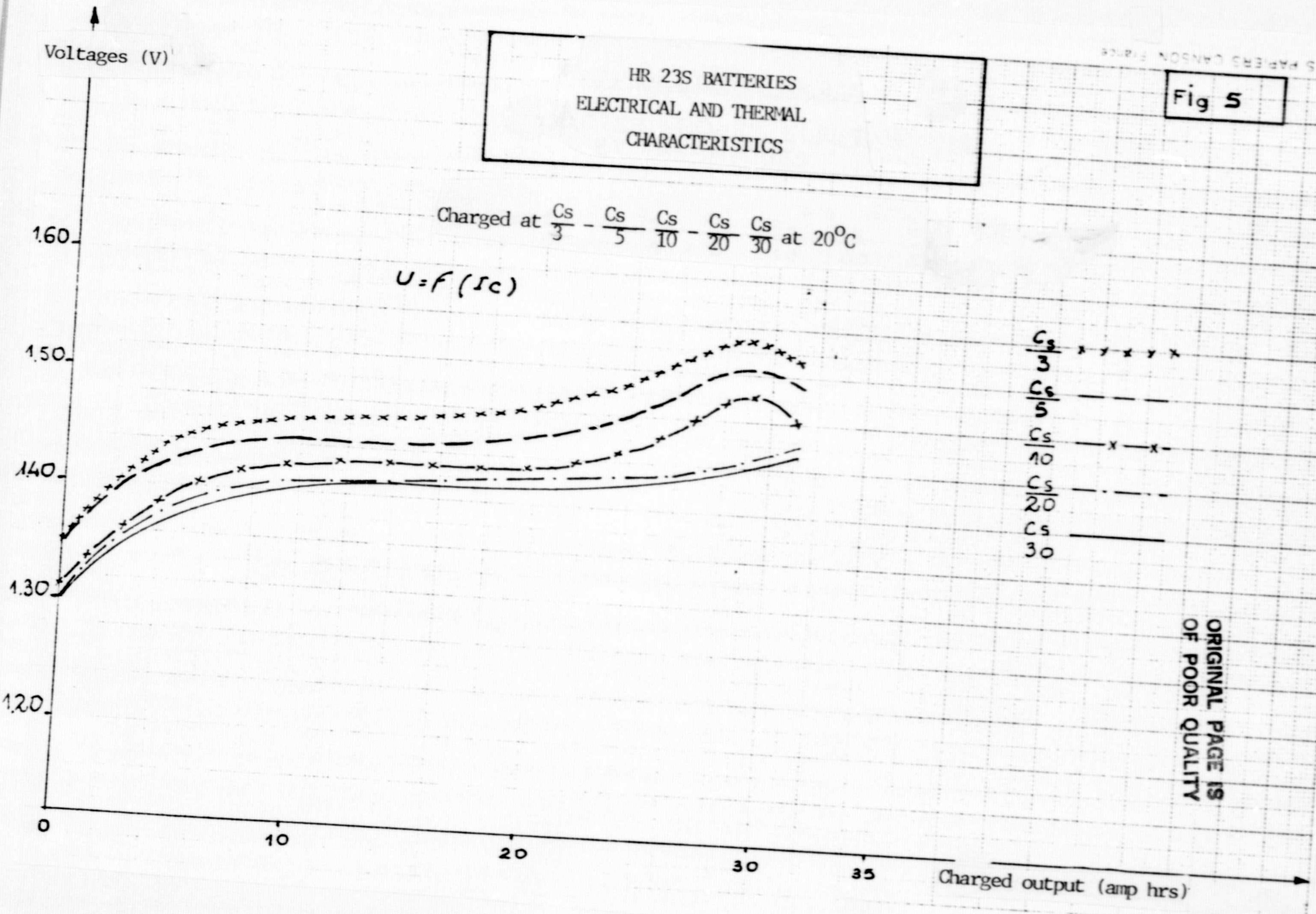


Fig 5
HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS
Charged at $\frac{Cs}{3}$ - $\frac{Cs}{5}$ $\frac{Cs}{10}$ - $\frac{Cs}{20}$ $\frac{Cs}{30}$ at 20°C
U=f(Ic)
Voltages (V)
1.60
1.50
1.40
1.30
1.20
0
10
20
30
35
Charged output (amp hrs)
$\frac{Cs}{3}$
$\frac{Cs}{5}$
$\frac{Cs}{10}$
$\frac{Cs}{20}$
$\frac{Cs}{30}$

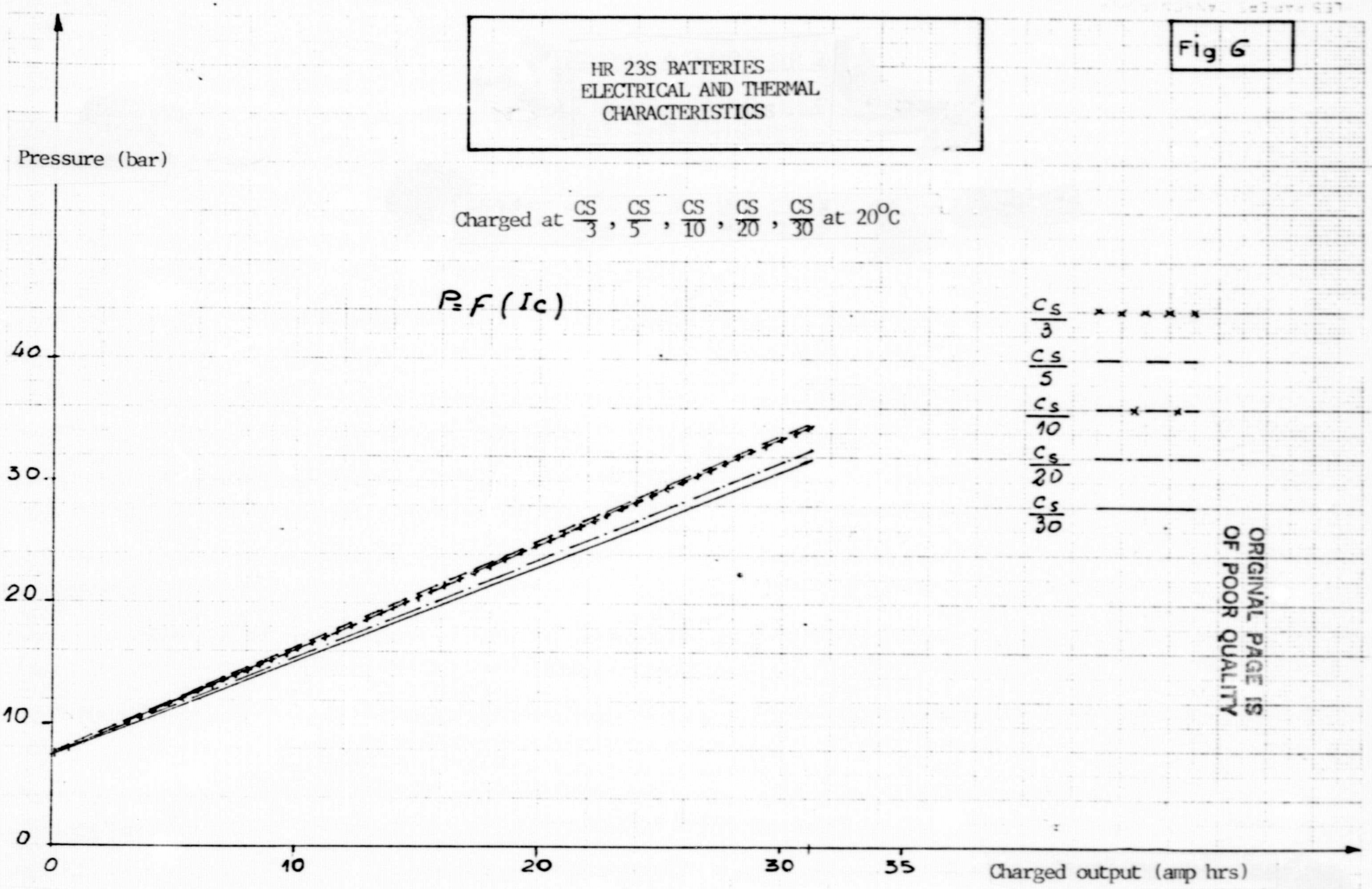


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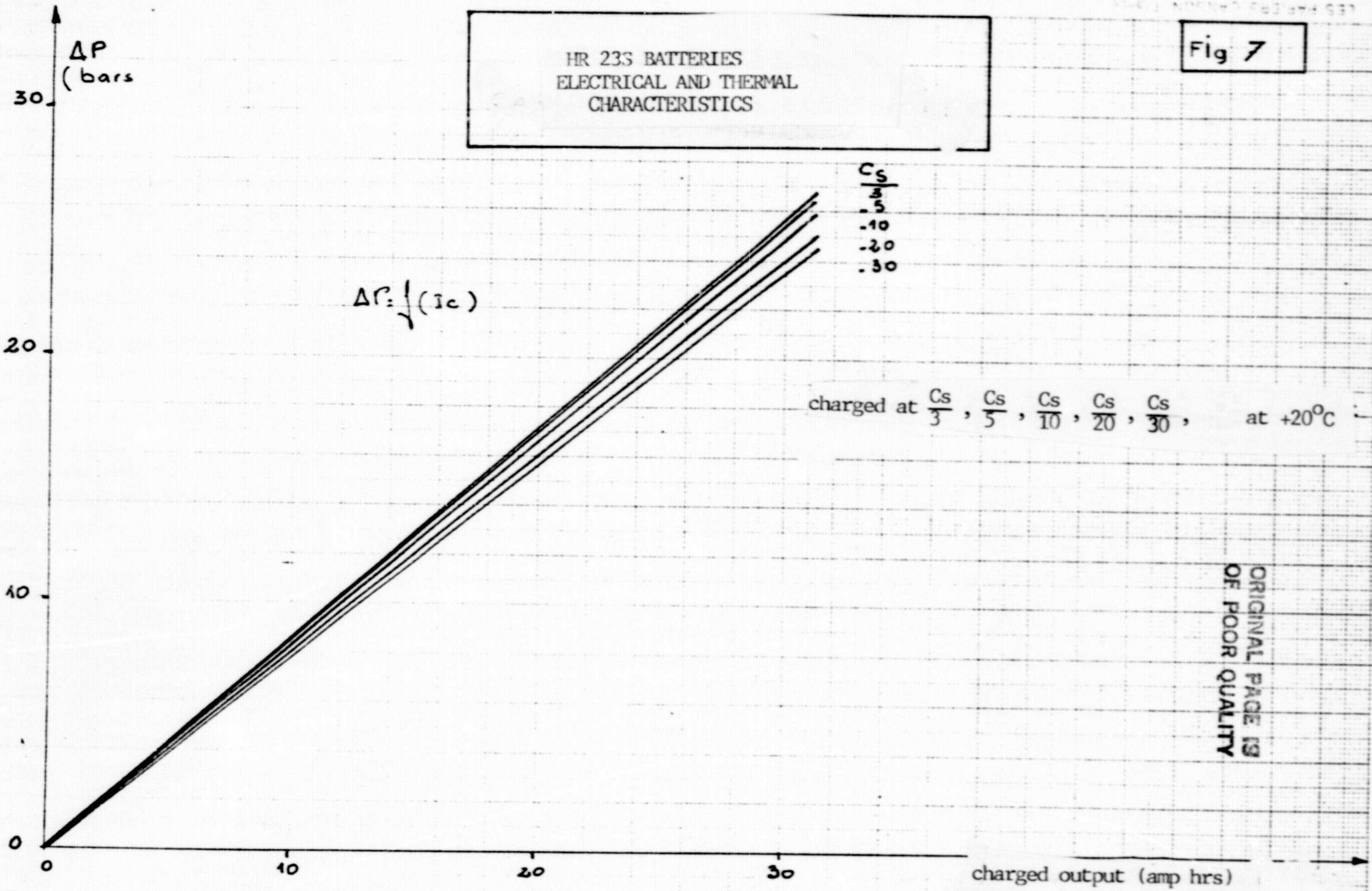
Fig 7

HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS



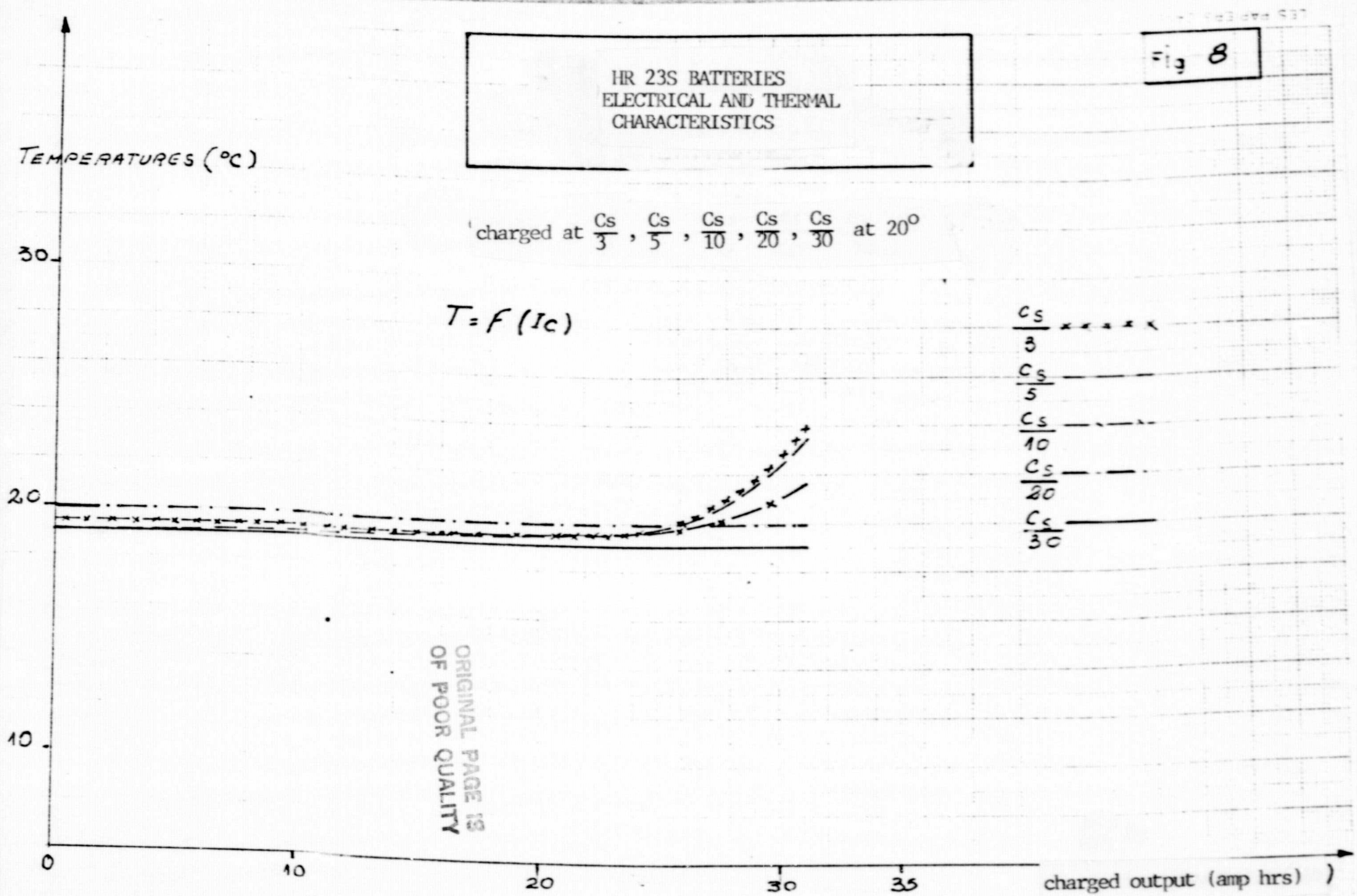


Fig 8
HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS
charged at Cs/3 , Cs/5 , Cs/10 , Cs/20 , Cs/30 at 20°
T = F (Ic)
TEMPERATURES (°C)
30
20
10
0
10
20
30
35
charged output (amp hrs)
Cs/3
Cs/5
Cs/10
Cs/20
Cs/30

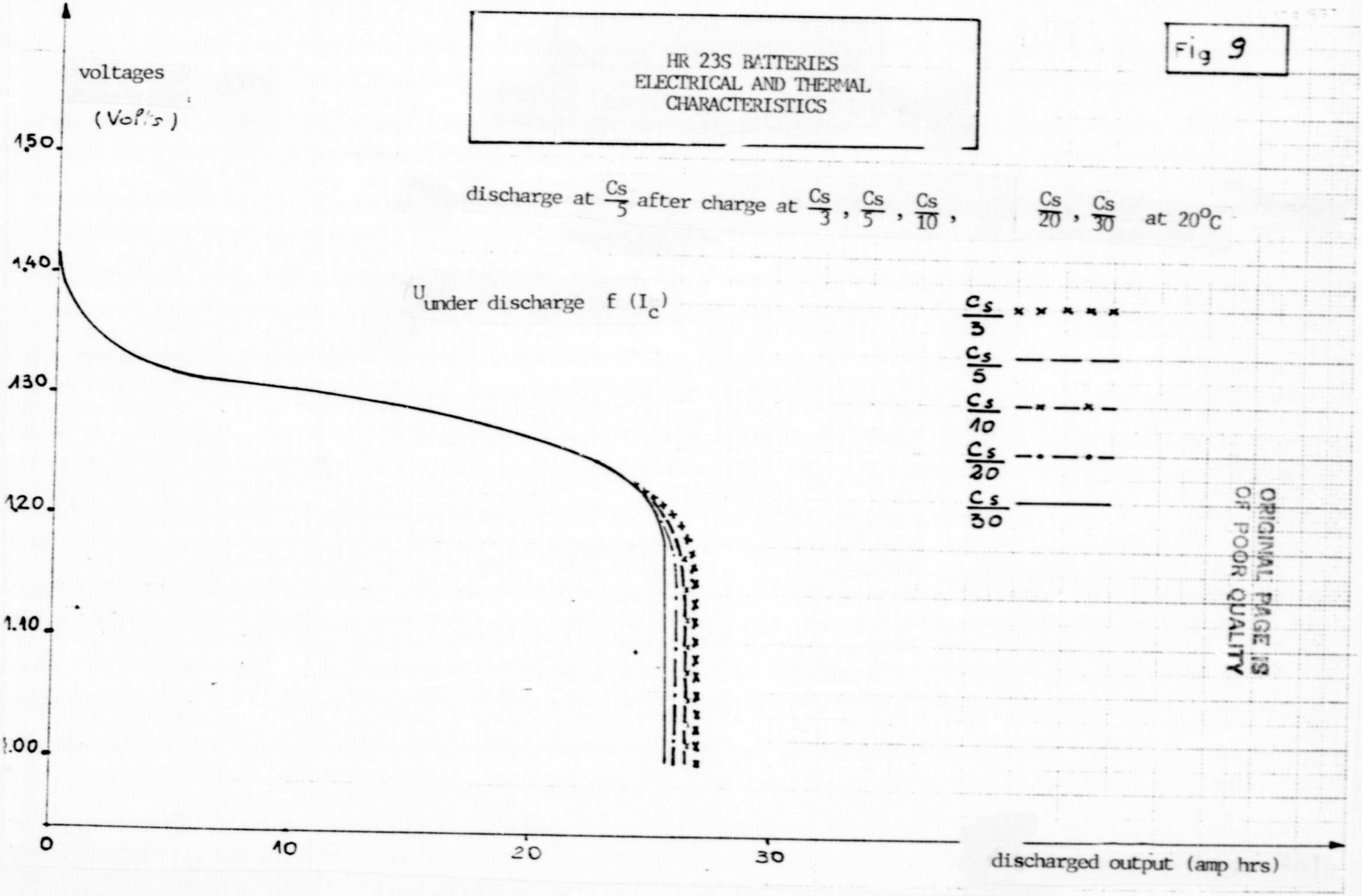


Fig 9
HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS
discharge at $\frac{Cs}{5}$ after charge at $\frac{Cs}{3}$, $\frac{Cs}{5}$, $\frac{Cs}{10}$, $\frac{Cs}{20}$, $\frac{Cs}{30}$ at 20°C
$U_{under\ discharge}$ f (I_c)
voltages
(Volts)
1.50
1.40
1.30
1.20
1.10
1.00
0
10
20
30
discharged output (amp hrs)
$\frac{Cs}{3}$
$\frac{Cs}{5}$
$\frac{Cs}{10}$
$\frac{Cs}{20}$
$\frac{Cs}{30}$

Fig 10

HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS

discharge at $\frac{Cs}{5}$ after charge at $\frac{Cs}{3}$, $\frac{Cs}{5}$, $\frac{Cs}{10}$, $\frac{Cs}{20}$, $\frac{Cs}{30}$ at 20°C

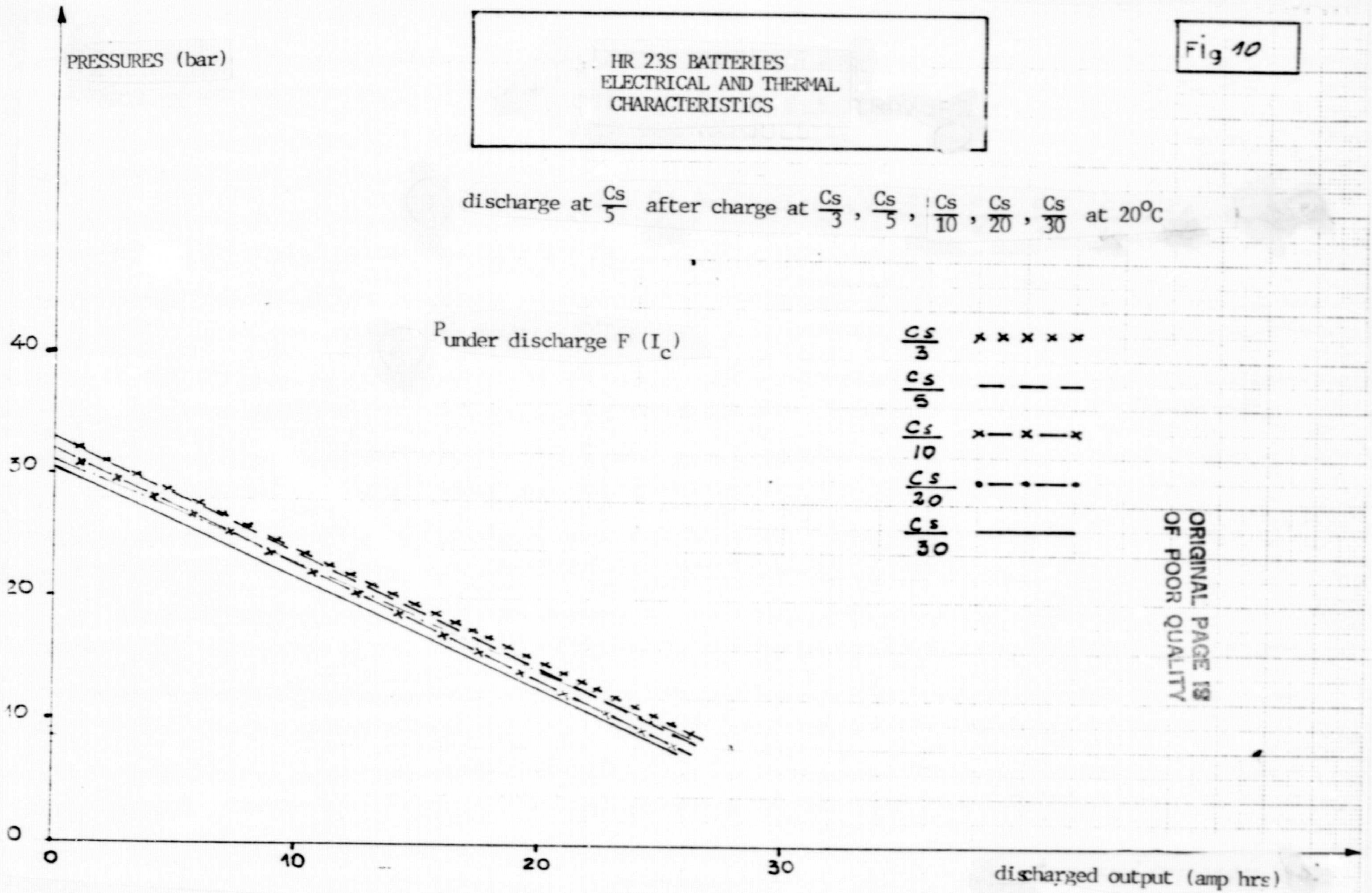


Fig 11

HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS

discharge at $\frac{Cs}{20}$, $\frac{Cs}{10}$, $\frac{Cs}{5}$, $\frac{Cs}{1}$, 2Cs after charging at $\frac{Cs}{10}$ at 20°C

U.f (Id)

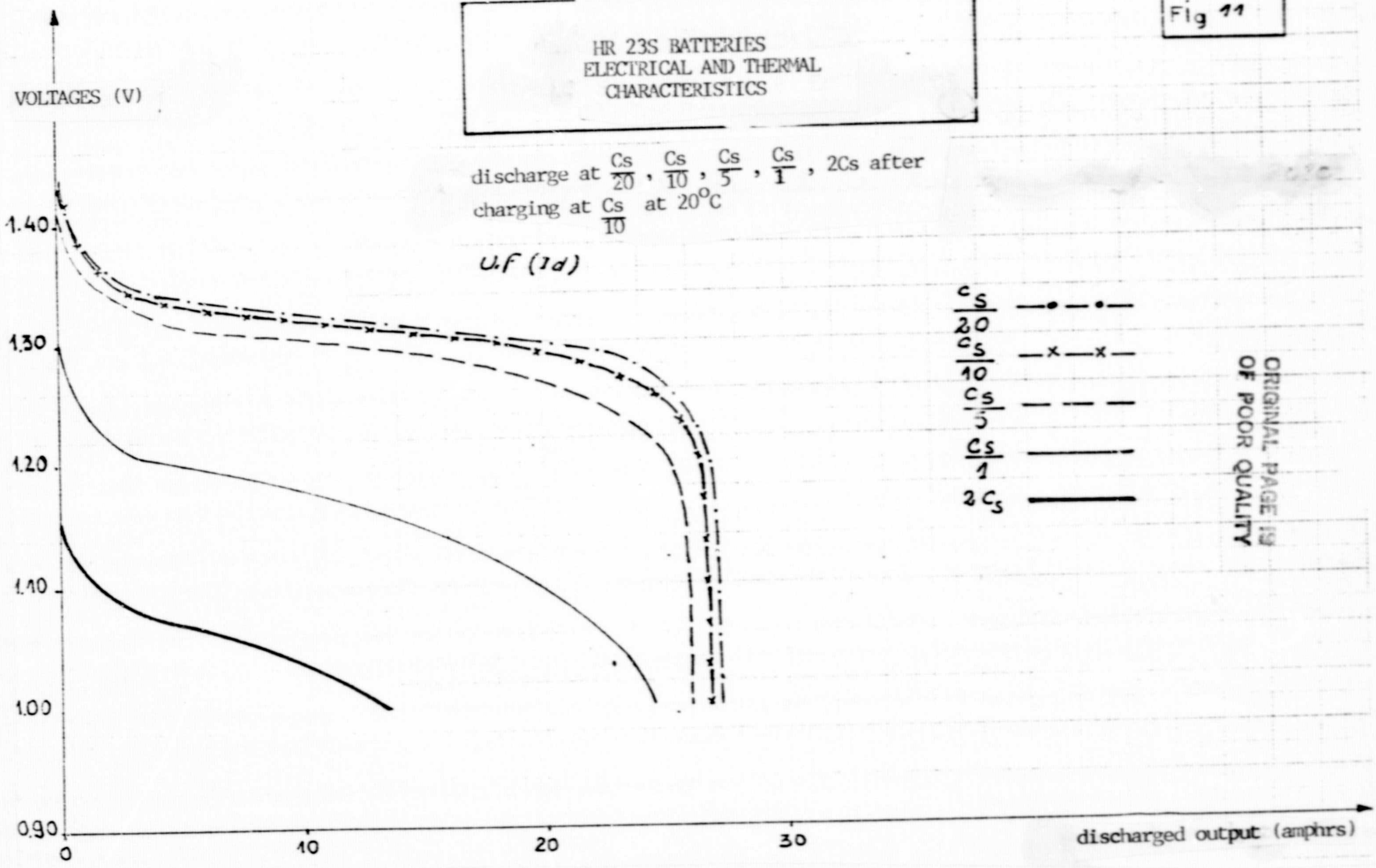


Fig 12

HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS

discharge at $\frac{Cs}{20}$, $\frac{Cs}{10}$, $\frac{Cs}{5}$, $\frac{Cs}{1}$, 2 Cs after charging at $\frac{Cs}{10}$ at 20°C

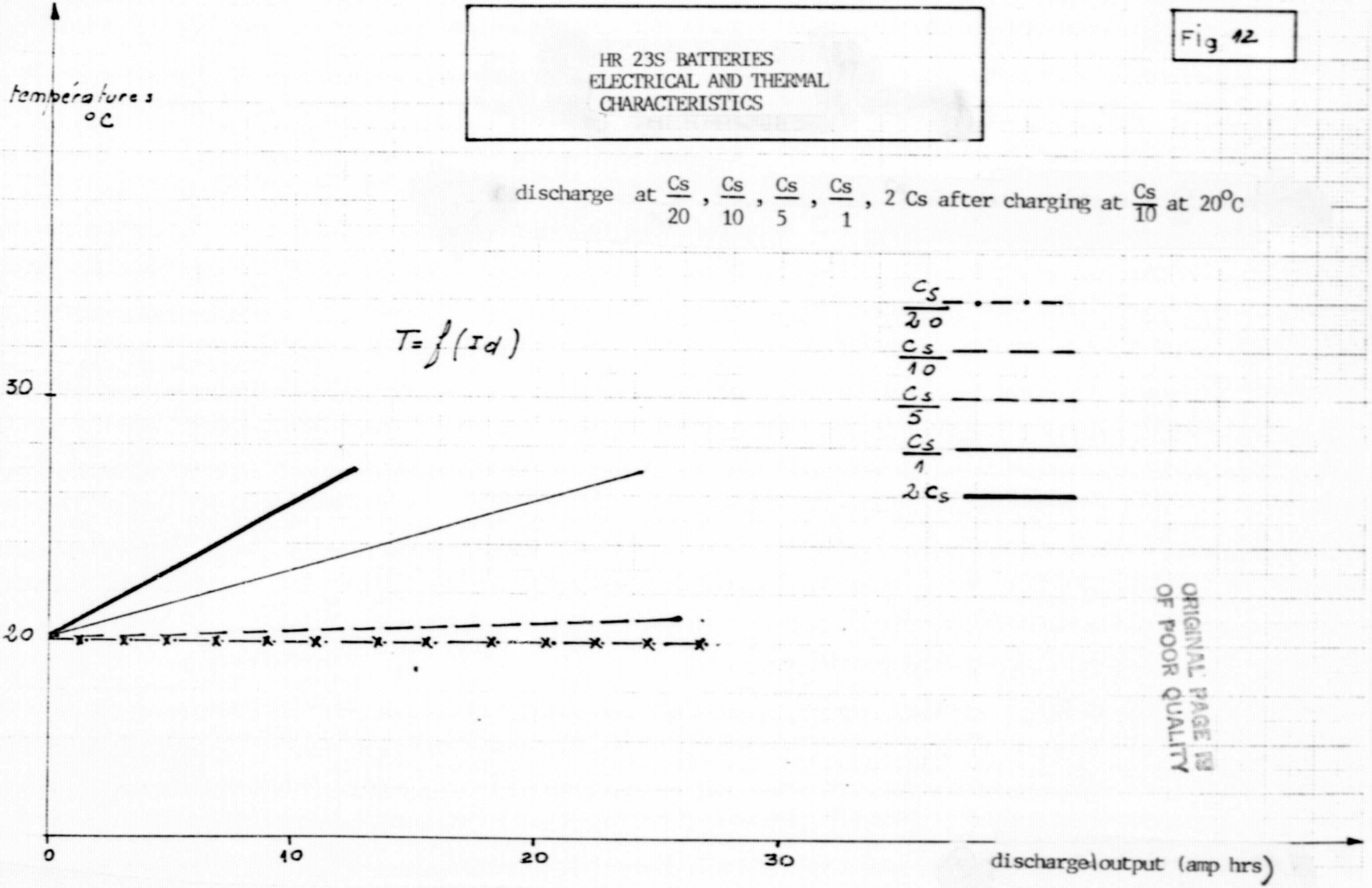
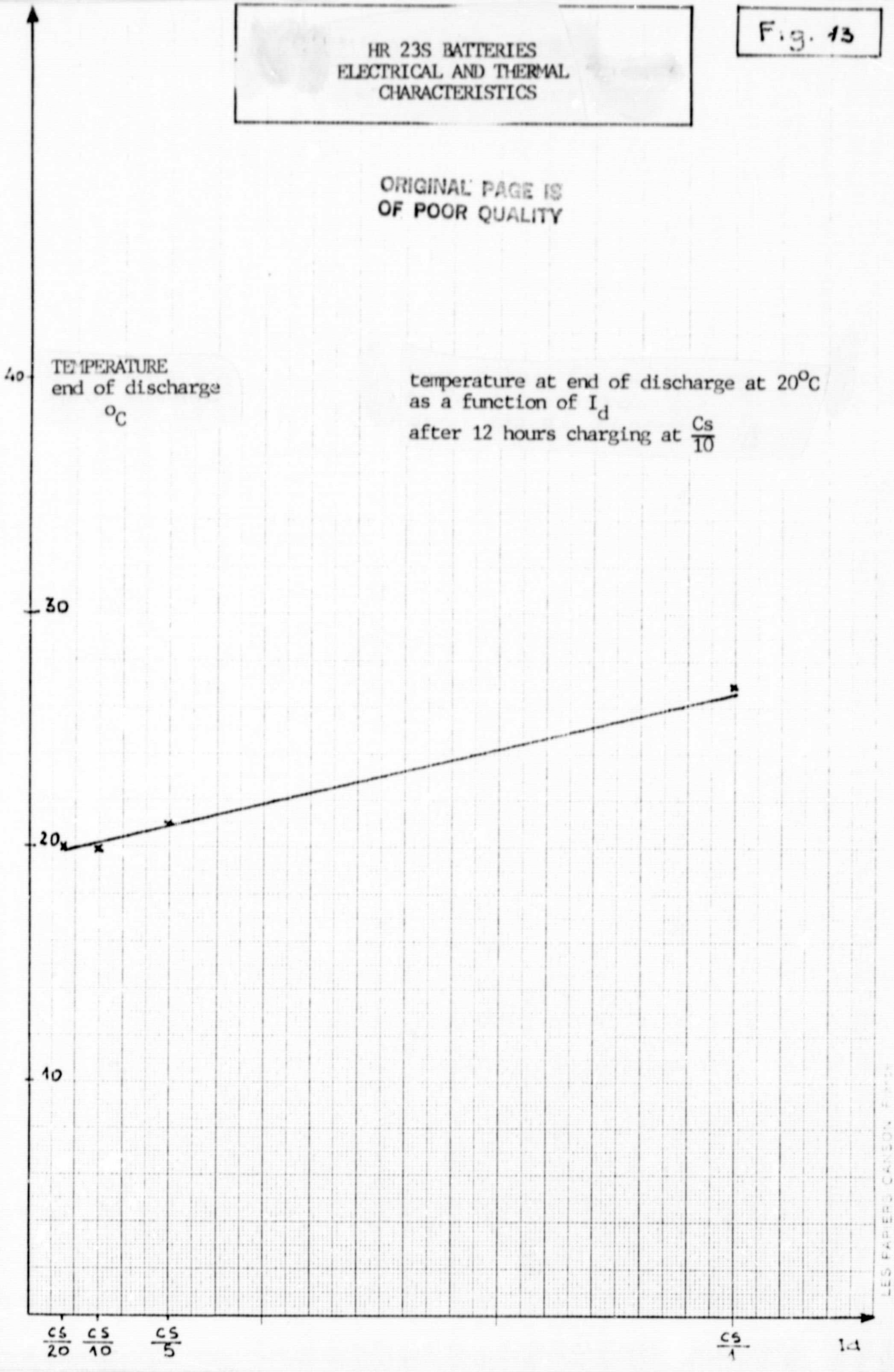


Fig. 13

HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS



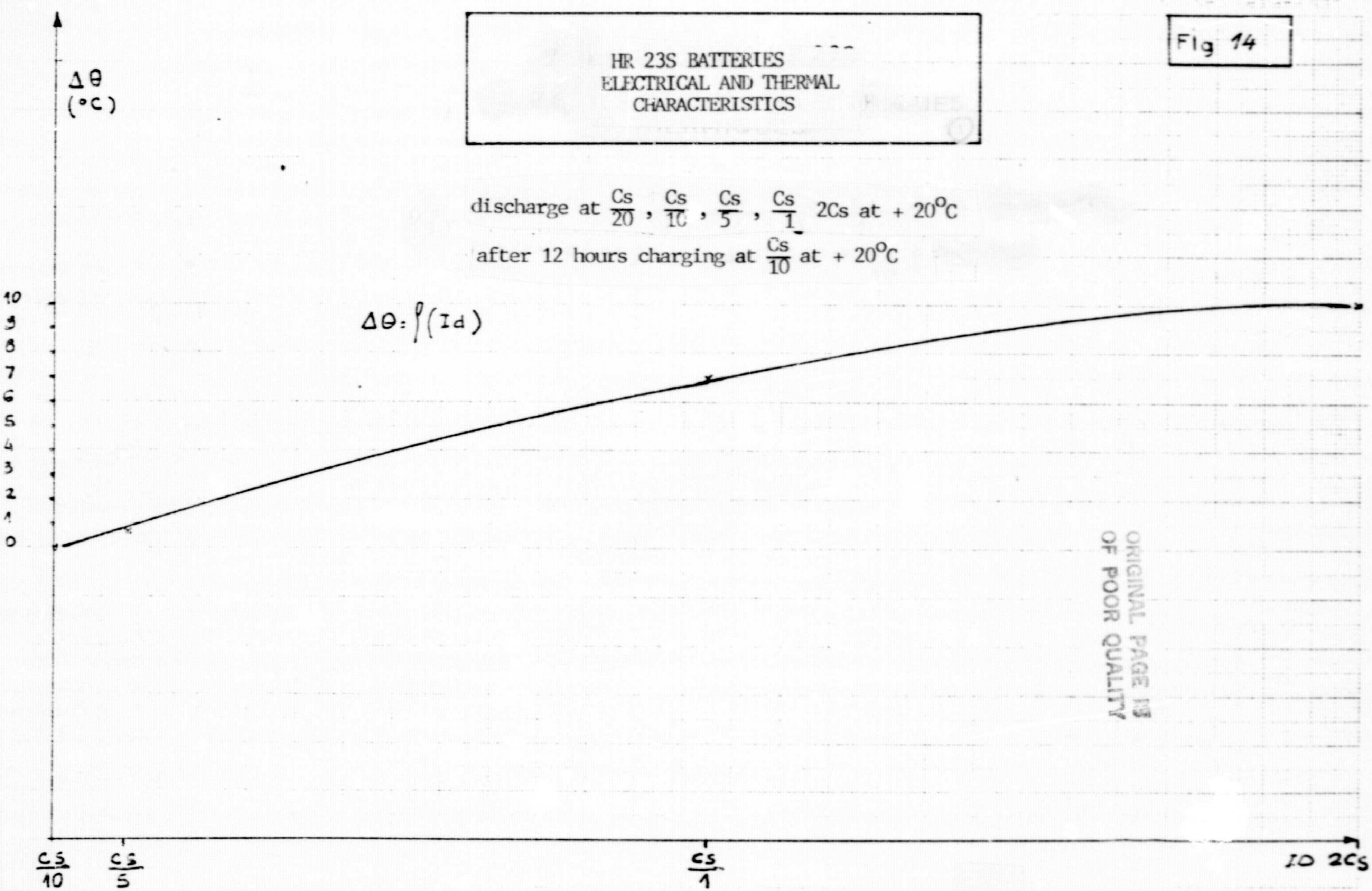


Fig 14
HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS
discharge at $\frac{Cs}{20}$, $\frac{Cs}{10}$, $\frac{Cs}{5}$, $\frac{Cs}{1}$, 2Cs at + 20^{o}C
after 12 hours charging at $\frac{Cs}{10}$ at + 20^{o}C
$\Delta\theta = f(Id)$
$\Delta\theta$ (°C)
10
9
8
7
6
5
4
3
2
1
0
$\frac{Cs}{10}$
$\frac{Cs}{5}$
$\frac{Cs}{1}$
10 2Cs

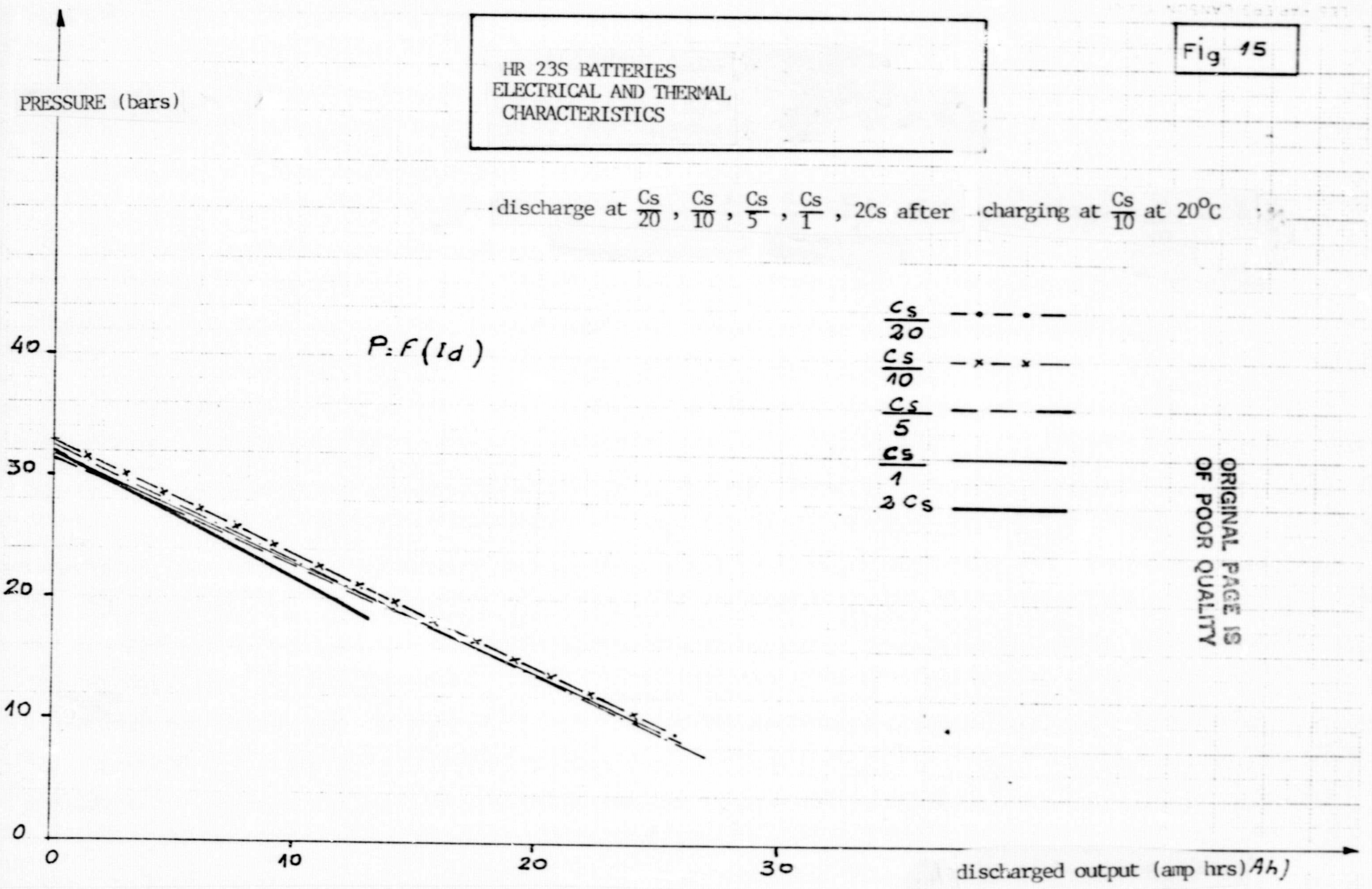


Fig 15
HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS
PRESSURE (bars)
· discharge at $\frac{Cs}{20}$, $\frac{Cs}{10}$, $\frac{Cs}{5}$, $\frac{Cs}{1}$, 2Cs after · charging at $\frac{Cs}{10}$ at 20°C
P: F(Id)
$\frac{Cs}{20}$
$\frac{Cs}{10}$
$\frac{Cs}{5}$
$\frac{Cs}{1}$
2 Cs
40
30
20
10
0
0
10
20
30
discharged output (amp hrs) Ah)
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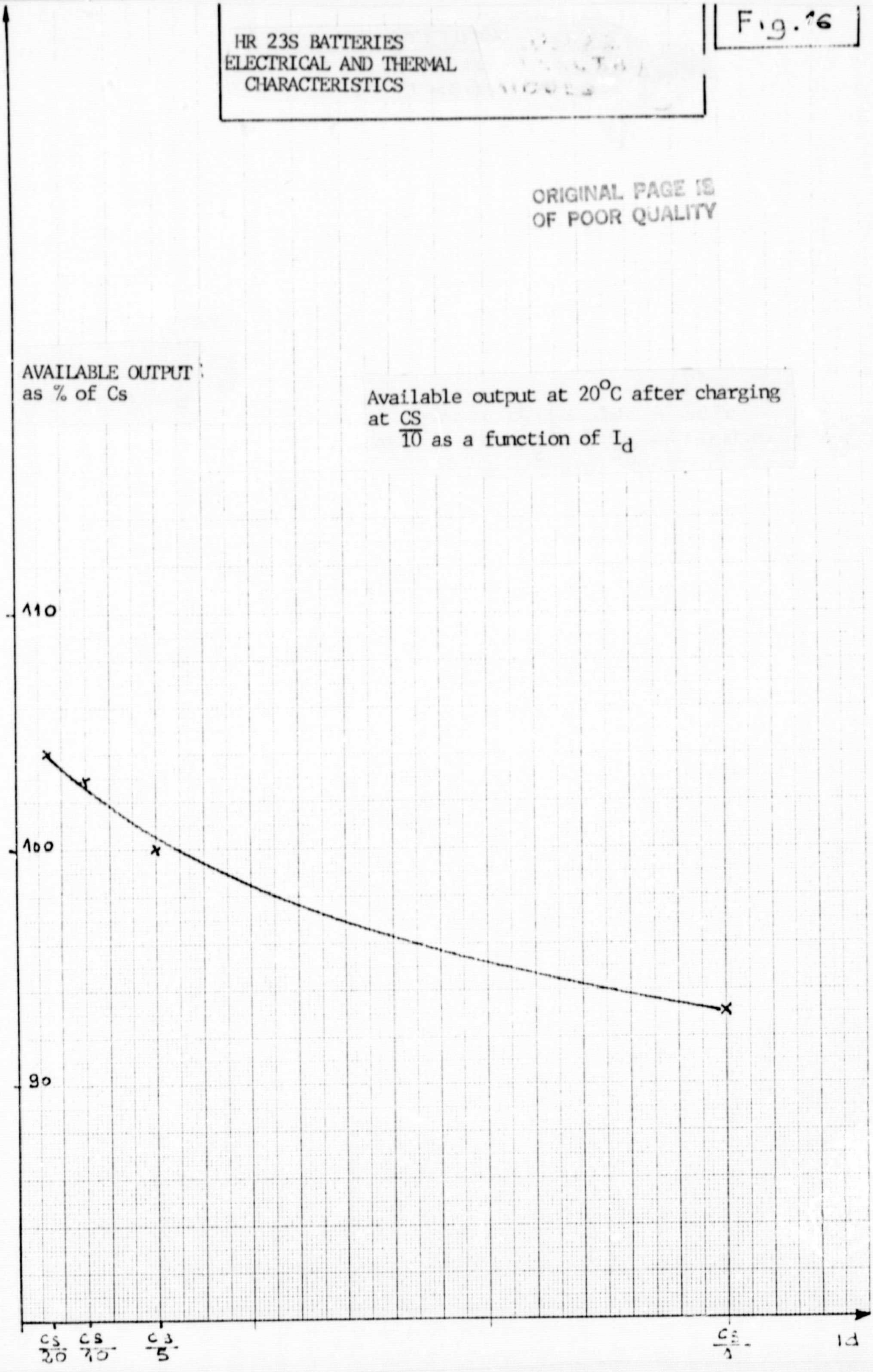
HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS

Fig. 16



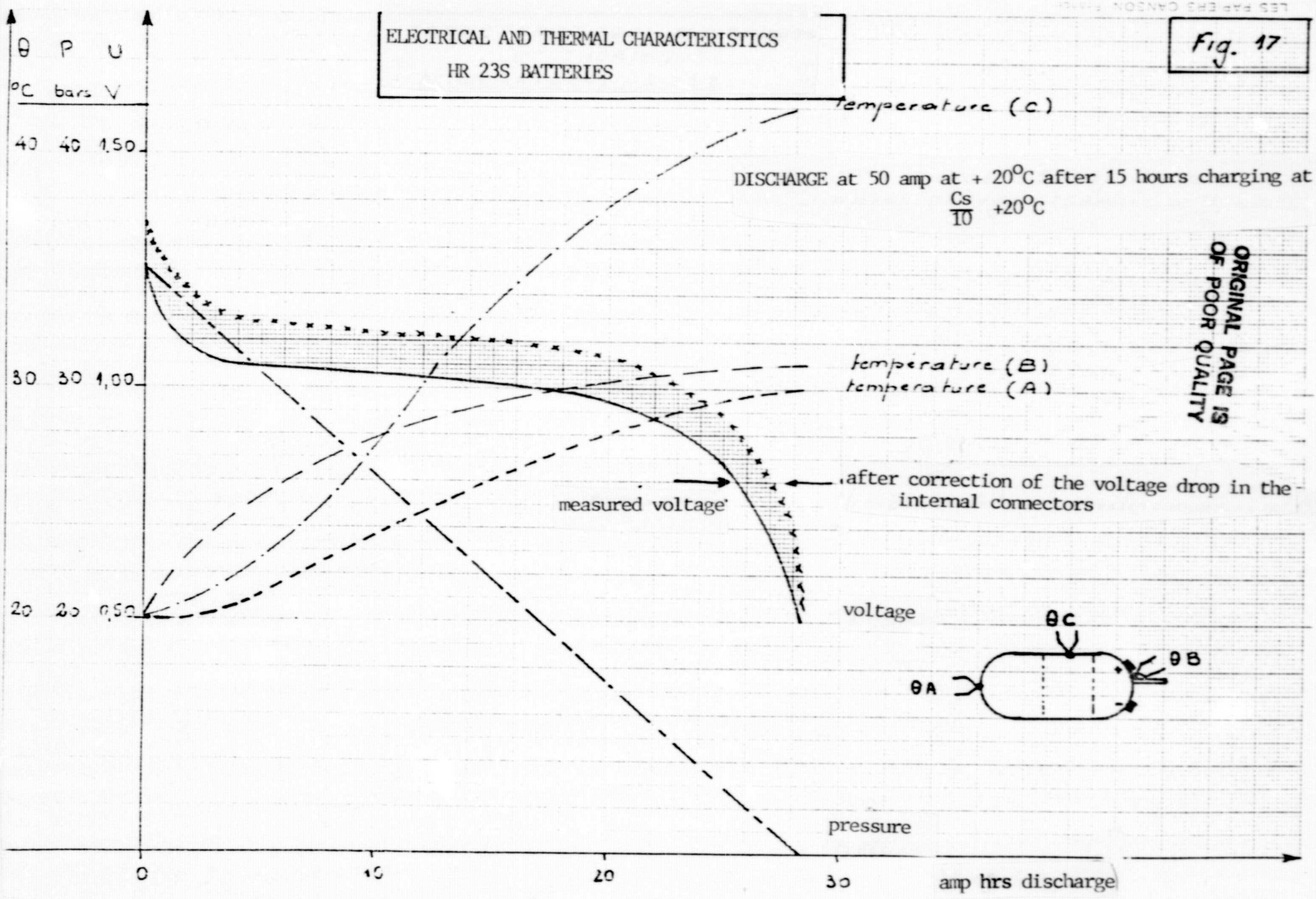


Fig. 17
ELECTRICAL AND THERMAL CHARACTERISTICS
HR 23S BATTERIES
θ P U
°C bars V
40 40 1,50
30 30 1,00
20 20 0,50
temperature (C)
DISCHARGE at 50 amp at + 20°C after 15 hours charging at
Cs/10 +20°C
temperature (B)
temperature (A)
after correction of the voltage drop in the internal connectors
measured voltage
voltage
pressure
θC
θB
θA
0
10
20
30
amp hrs discharge

Fig 18

HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS

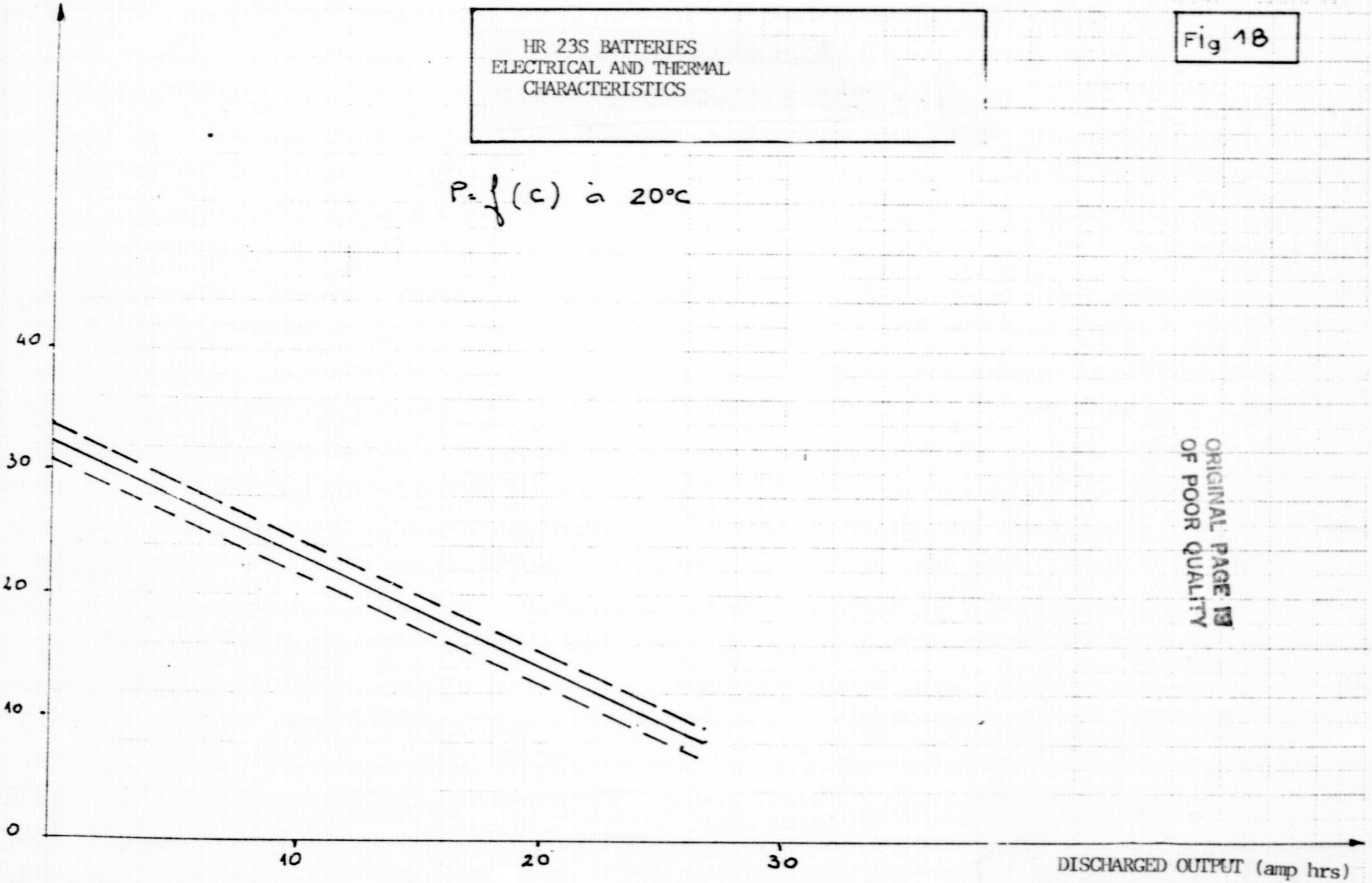


Fig 19

HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS

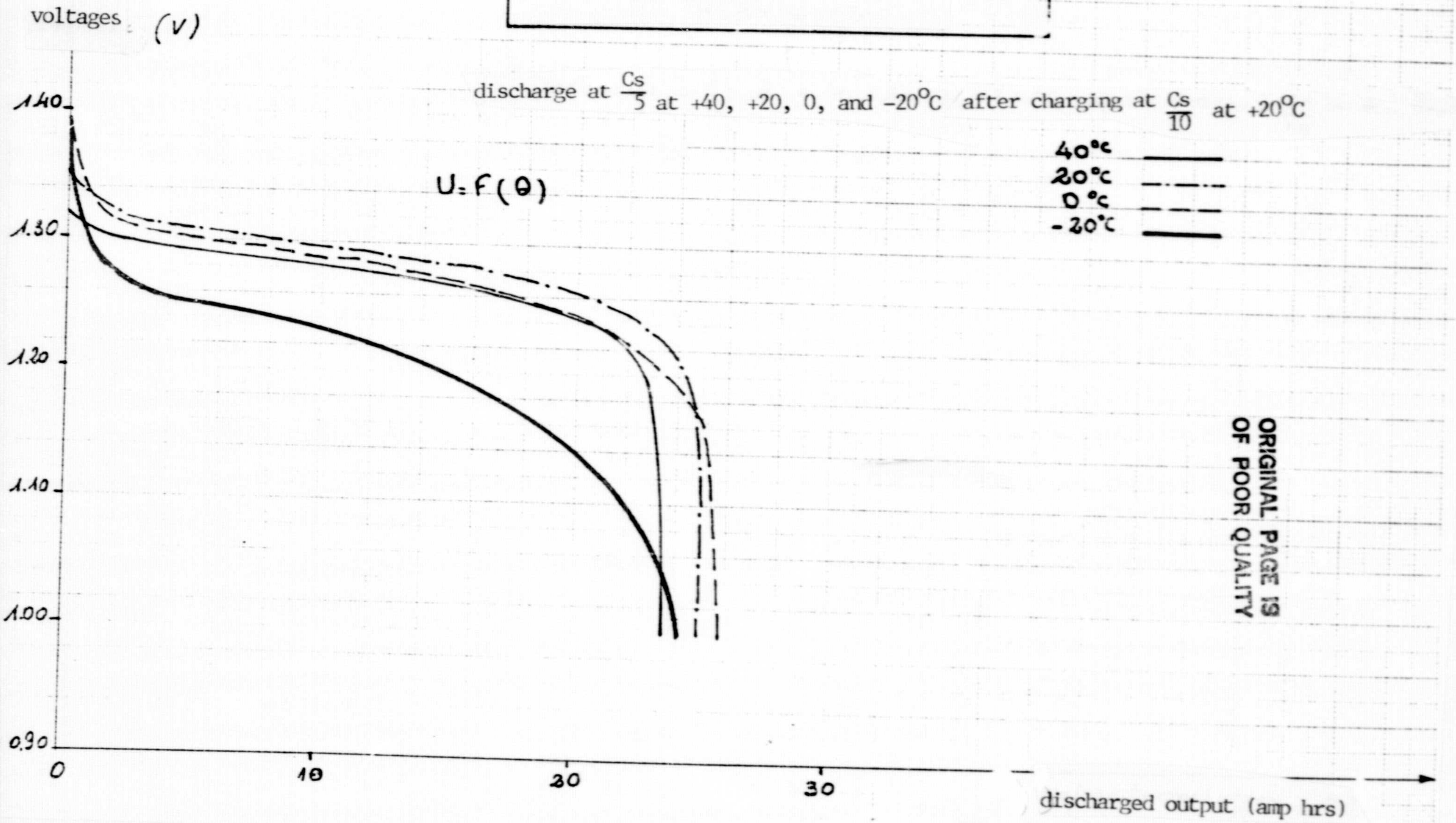
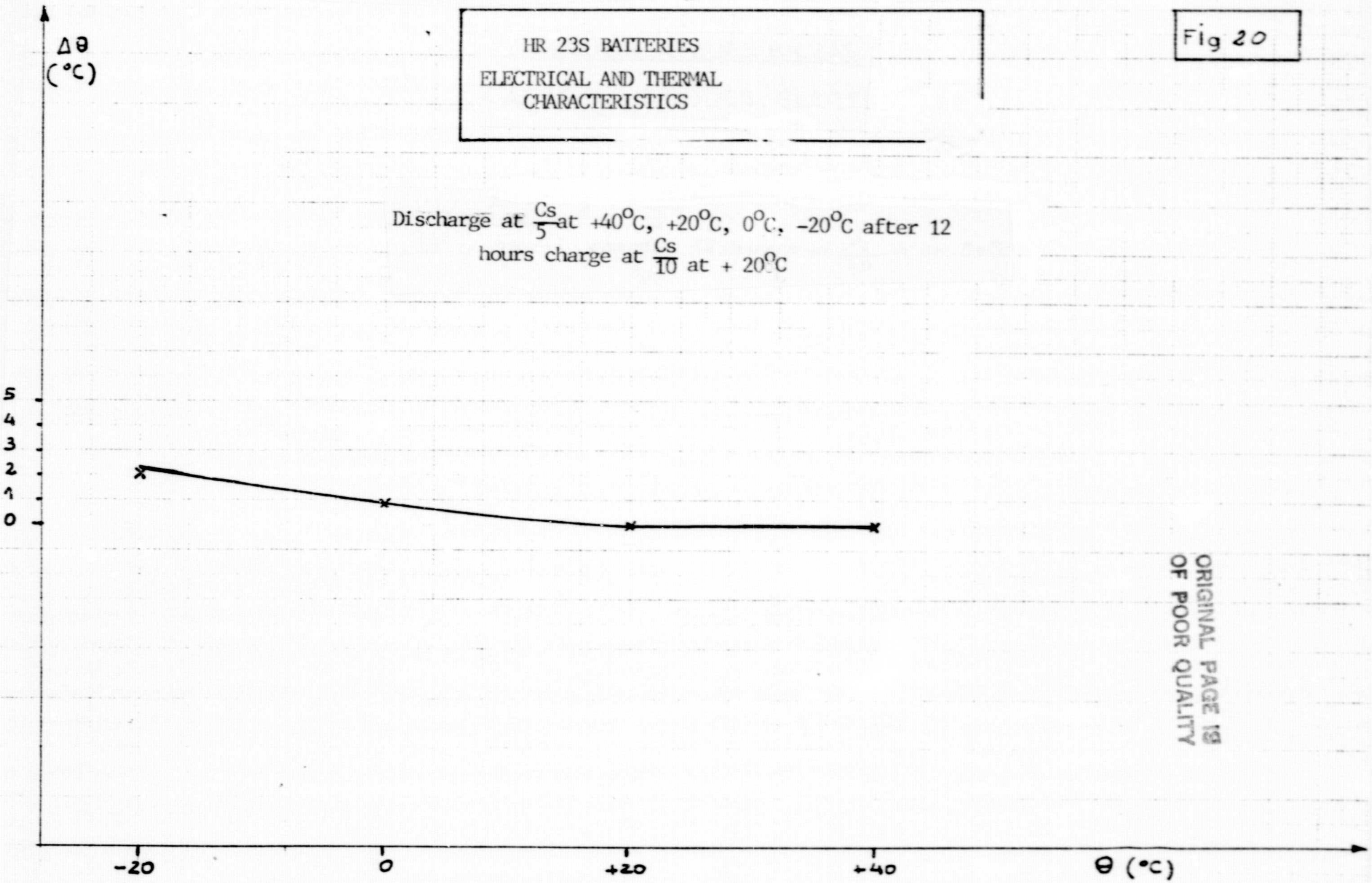


Fig 20

HR 23S BATTERIES

ELECTRICAL AND THERMAL CHARACTERISTICS



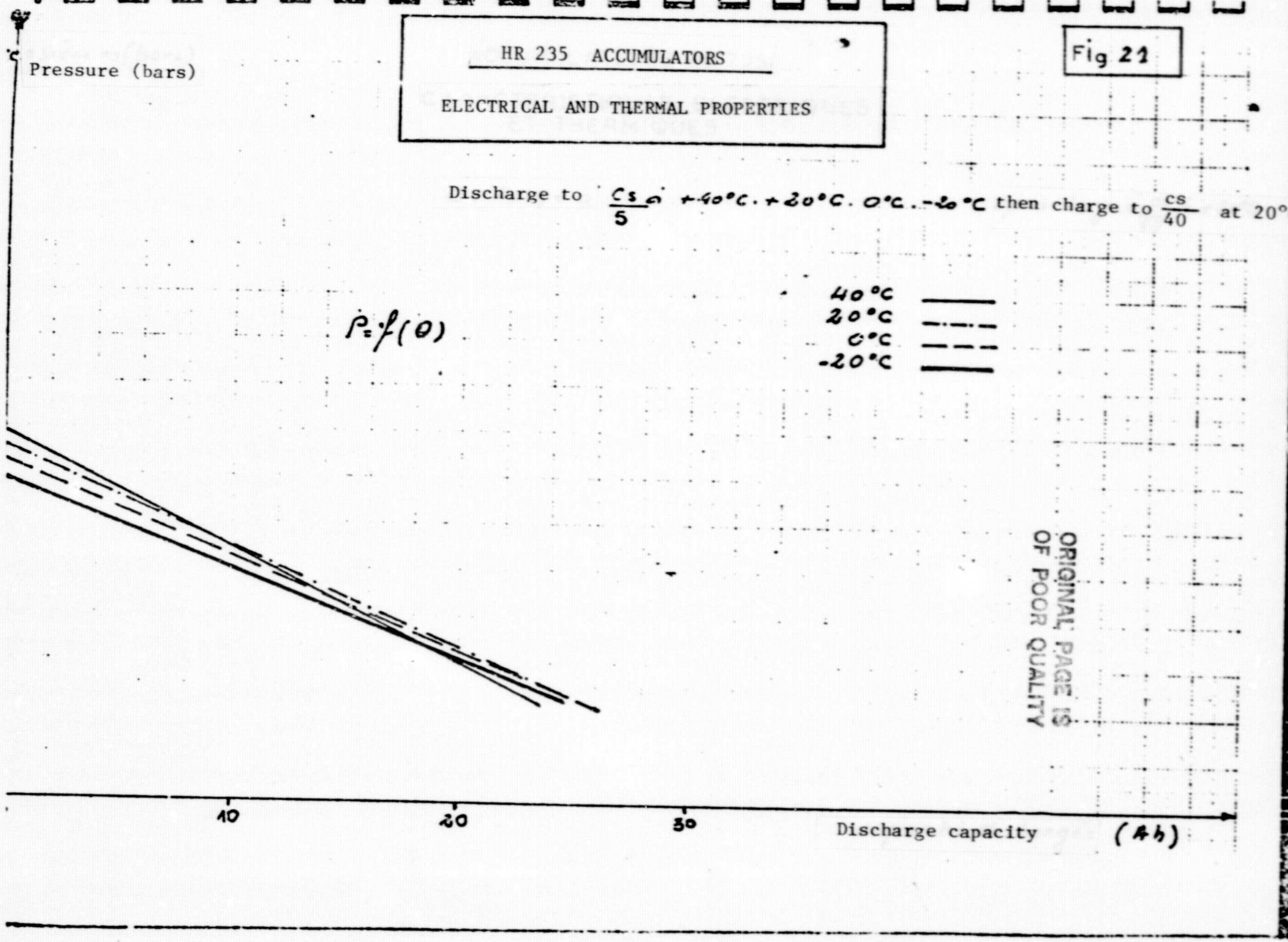
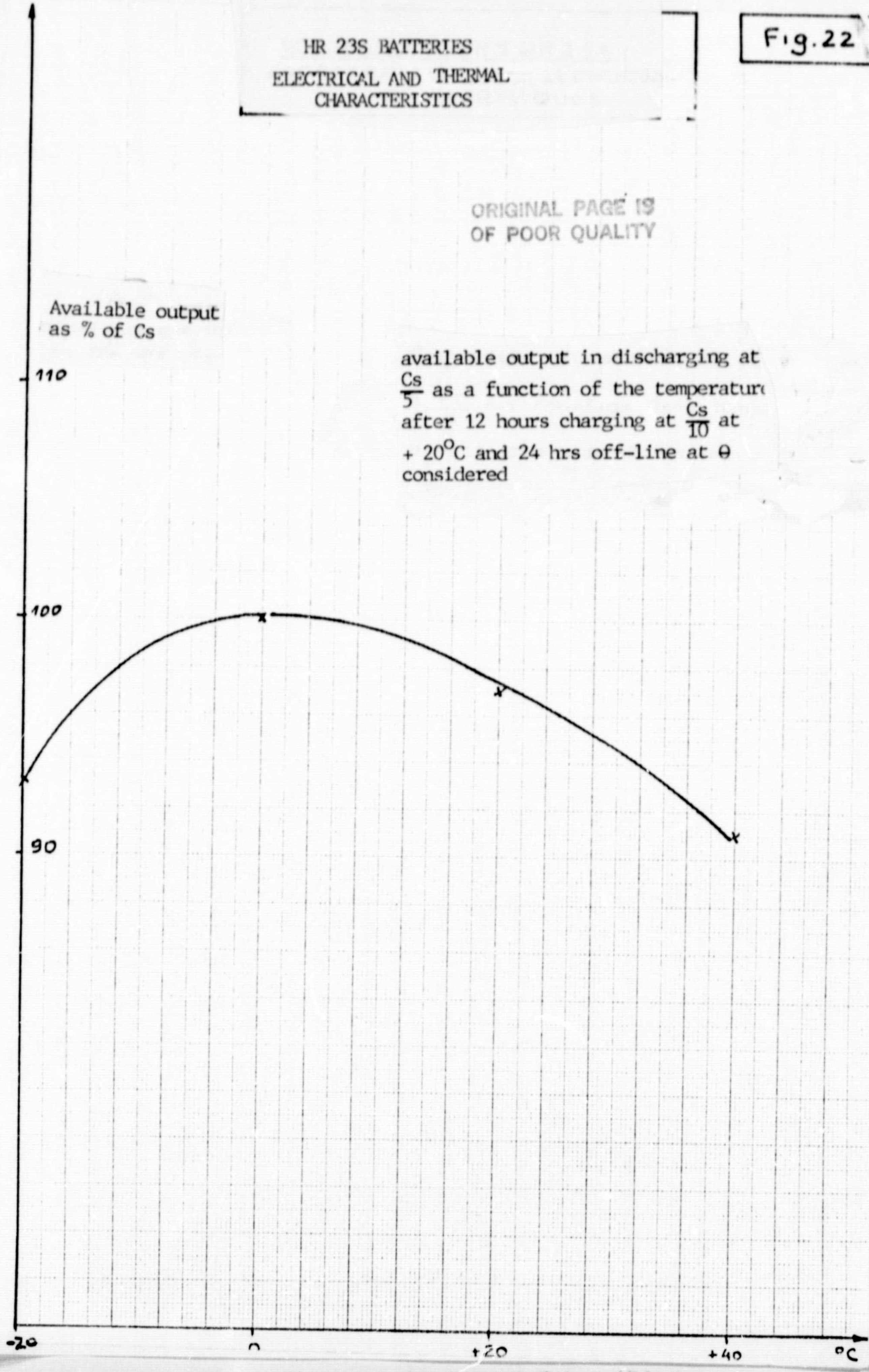


Fig 21
HR 235 ACCUMULATORS
ELECTRICAL AND THERMAL PROPERTIES
Pressure (bars)
Discharge to $\frac{Cs}{5}$ à +40°C. +20°C. 0°C. -20°C then charge to $\frac{cs}{40}$ at 20°C
$P = f(\theta)$
40°C
20°C
0°C
-20°C
10
20
30
Discharge capacity (Ah)

HR 23S BATTERIES

ELECTRICAL AND THERMAL CHARACTERISTICS

Fig.22



available output in discharging at $\frac{Cs}{5}$ as a function of the temperature after 12 hours charging at $\frac{Cs}{10}$ at $+ 20^{o}C$ and 24 hrs off-line at θ considered

Fig 23

HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS

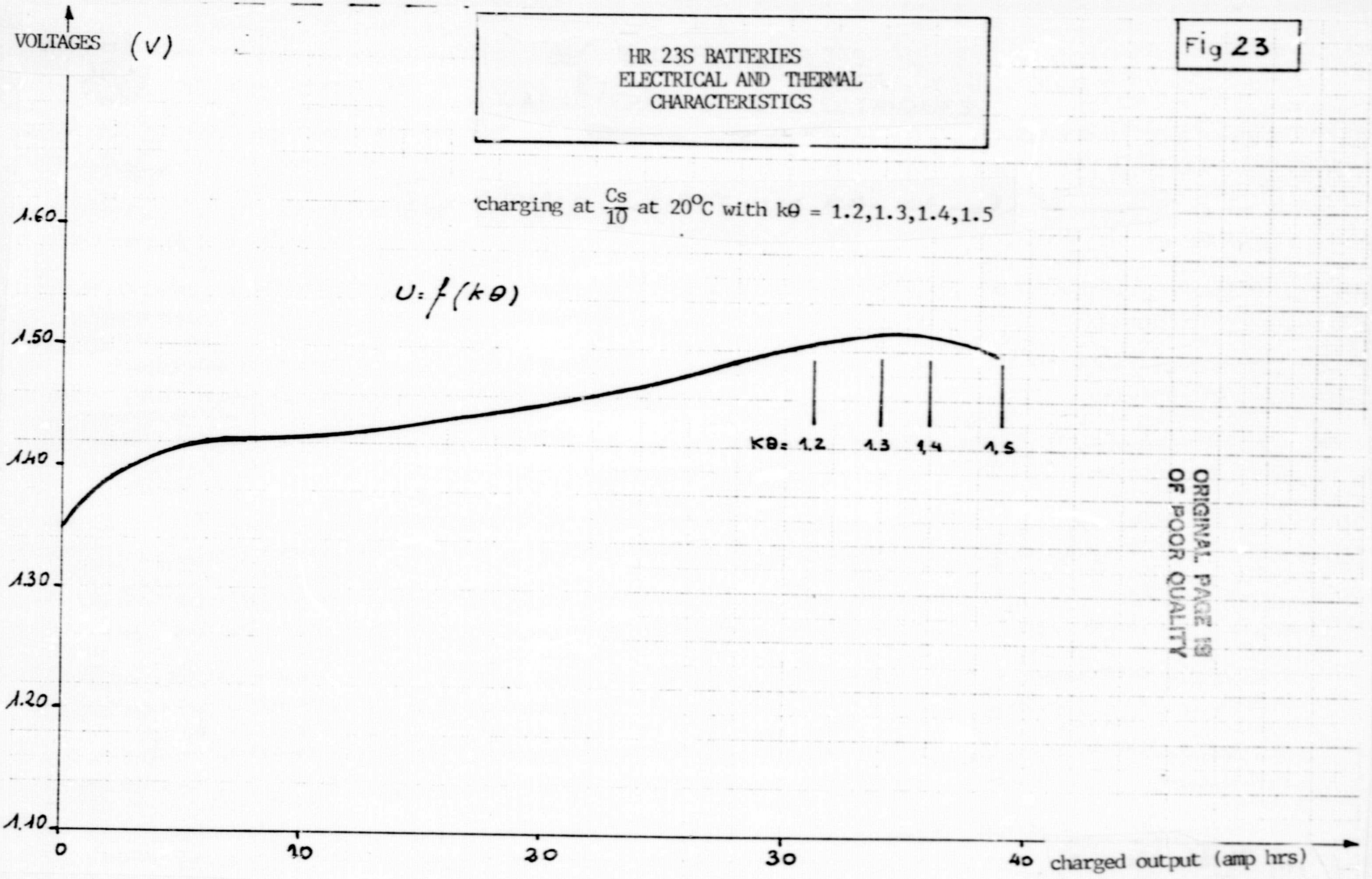


Fig 24

HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS

discharge at $\frac{Cs}{5}$ after charging at $\frac{Cs}{10}$ with $k\,\theta$ = 1.2,1.3,1.4,1.5

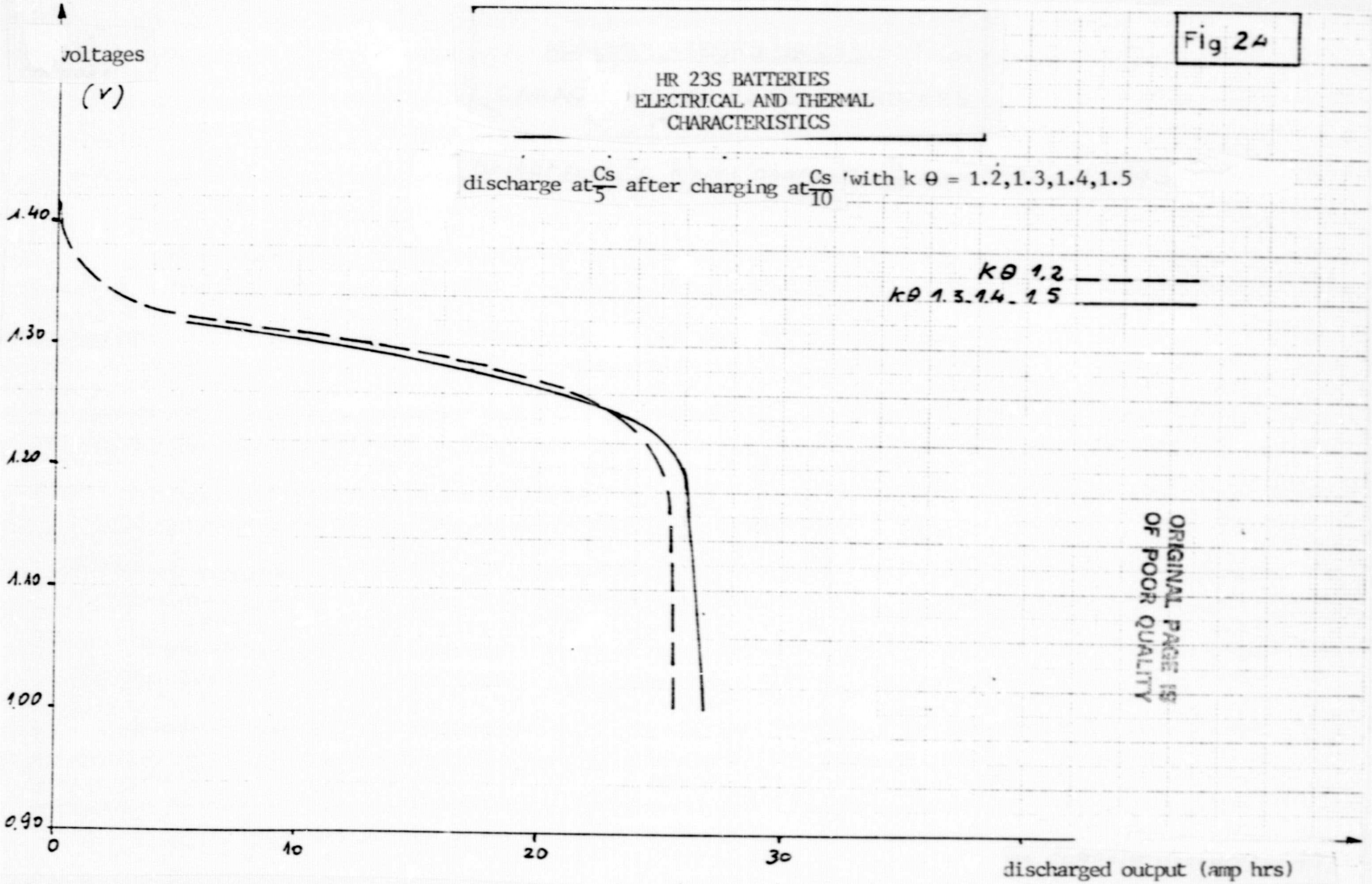


Fig 25

HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS

charge at $\frac{Cs}{10}$ at +20° with k θ = 1.2,1.3,1.4,1.5

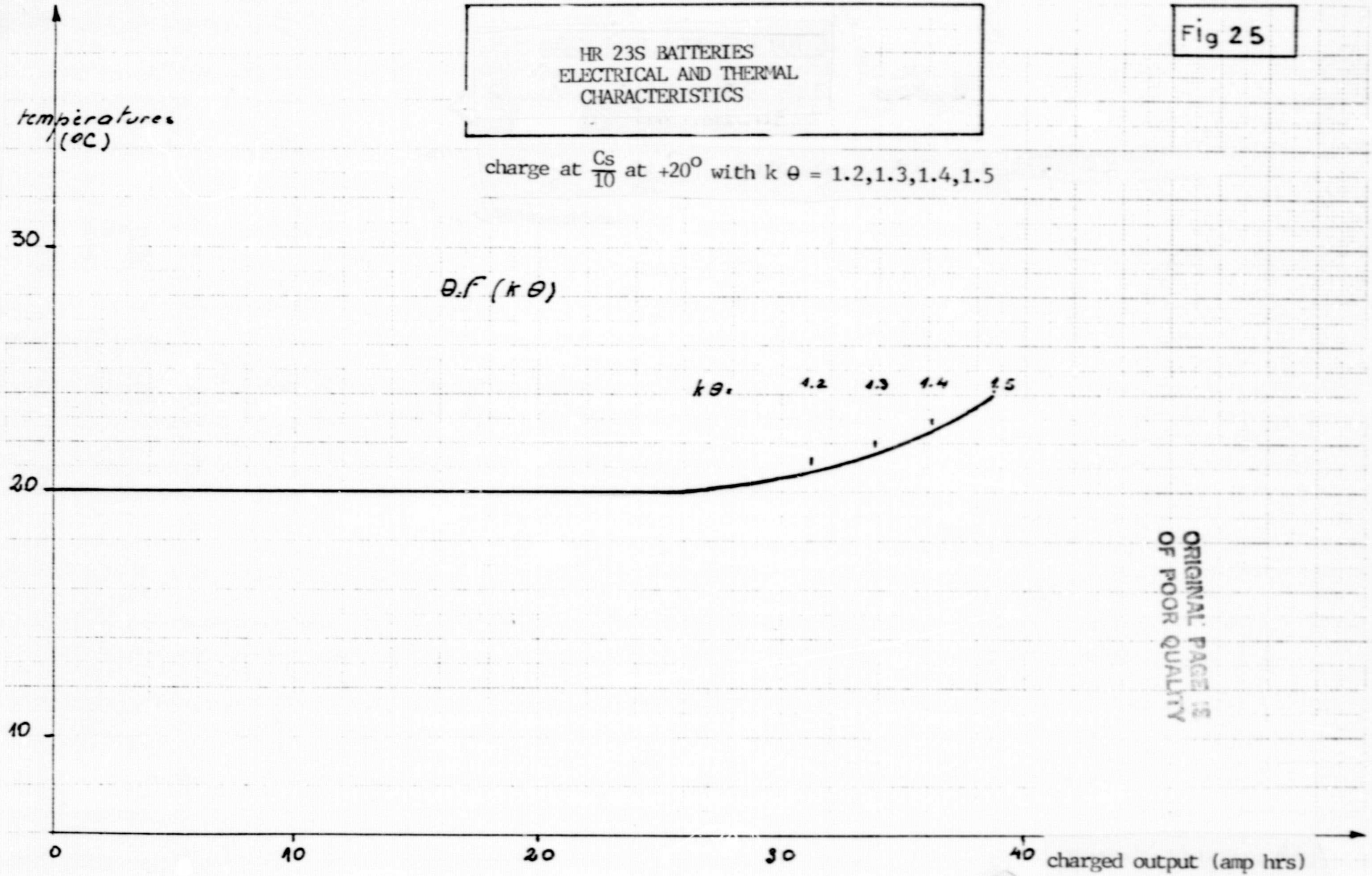
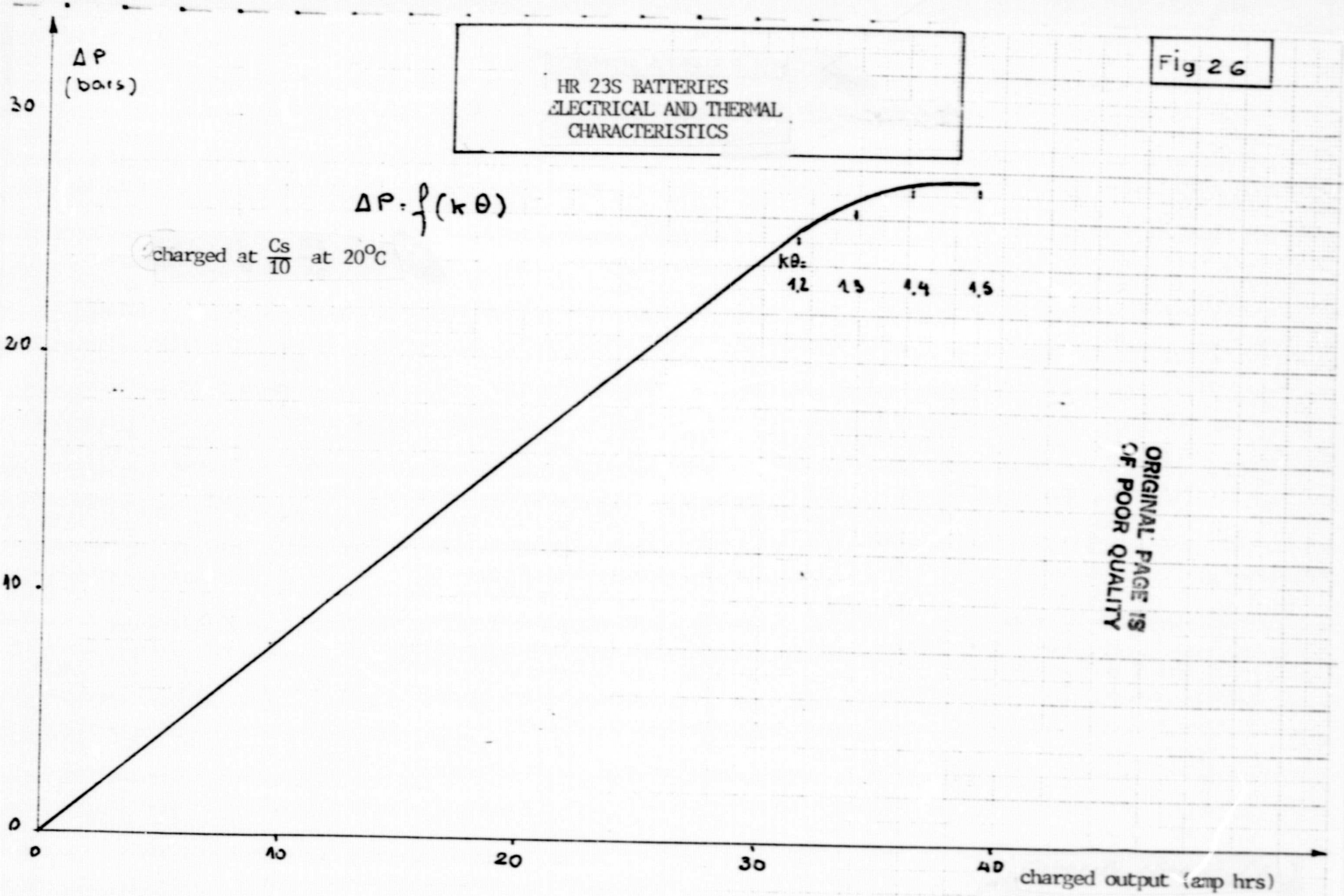


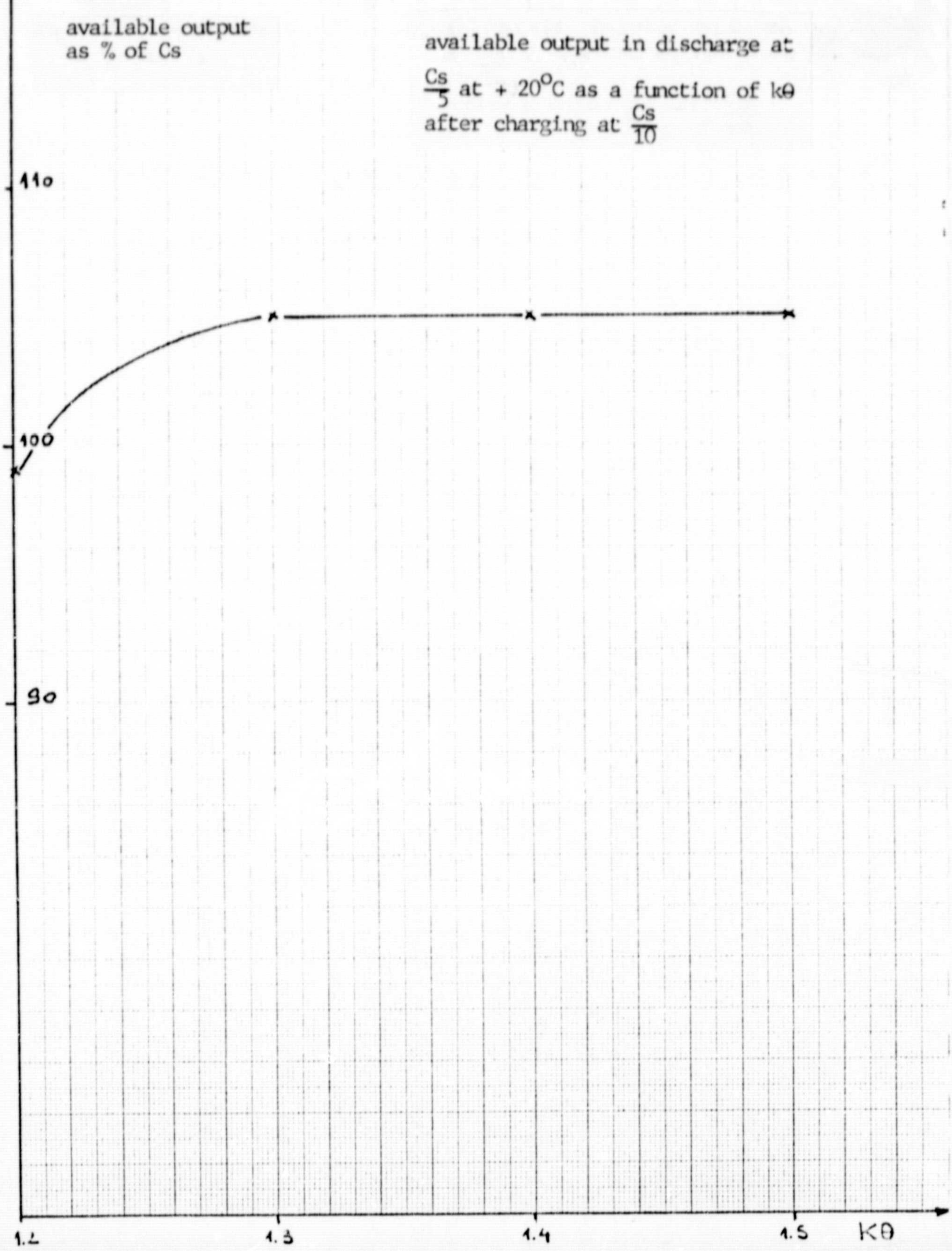
Fig 26



HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS
ΔP = f(kθ)
charged at Cs/10 at 20°C
ΔP
(bars)
30
20
10
0
kθ=
1,2
1,3
1,4
1,5
0
10
20
30
40
charged output (amp hrs)

HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS

Fig. 27



HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS

Fig. 2B

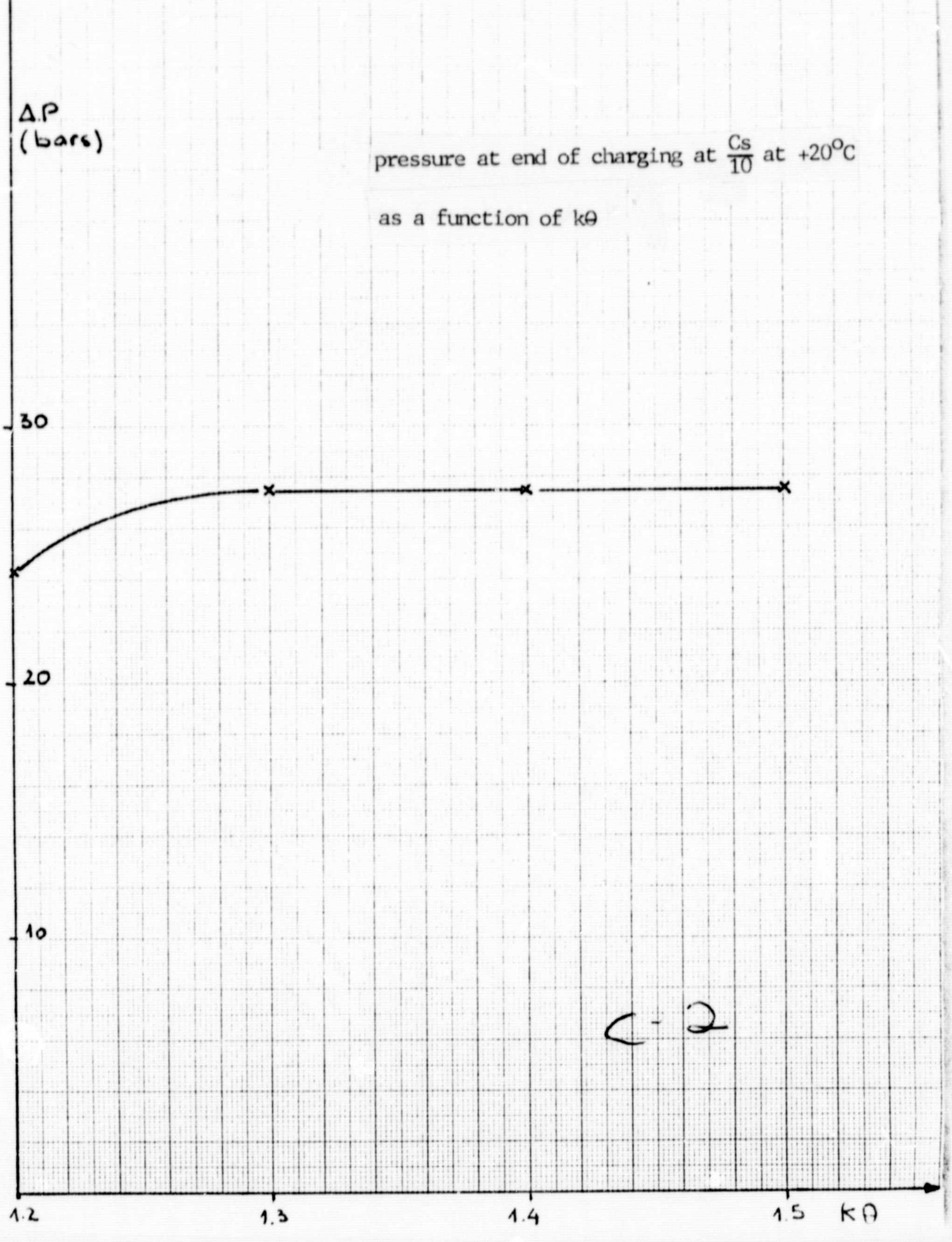


Fig. 29

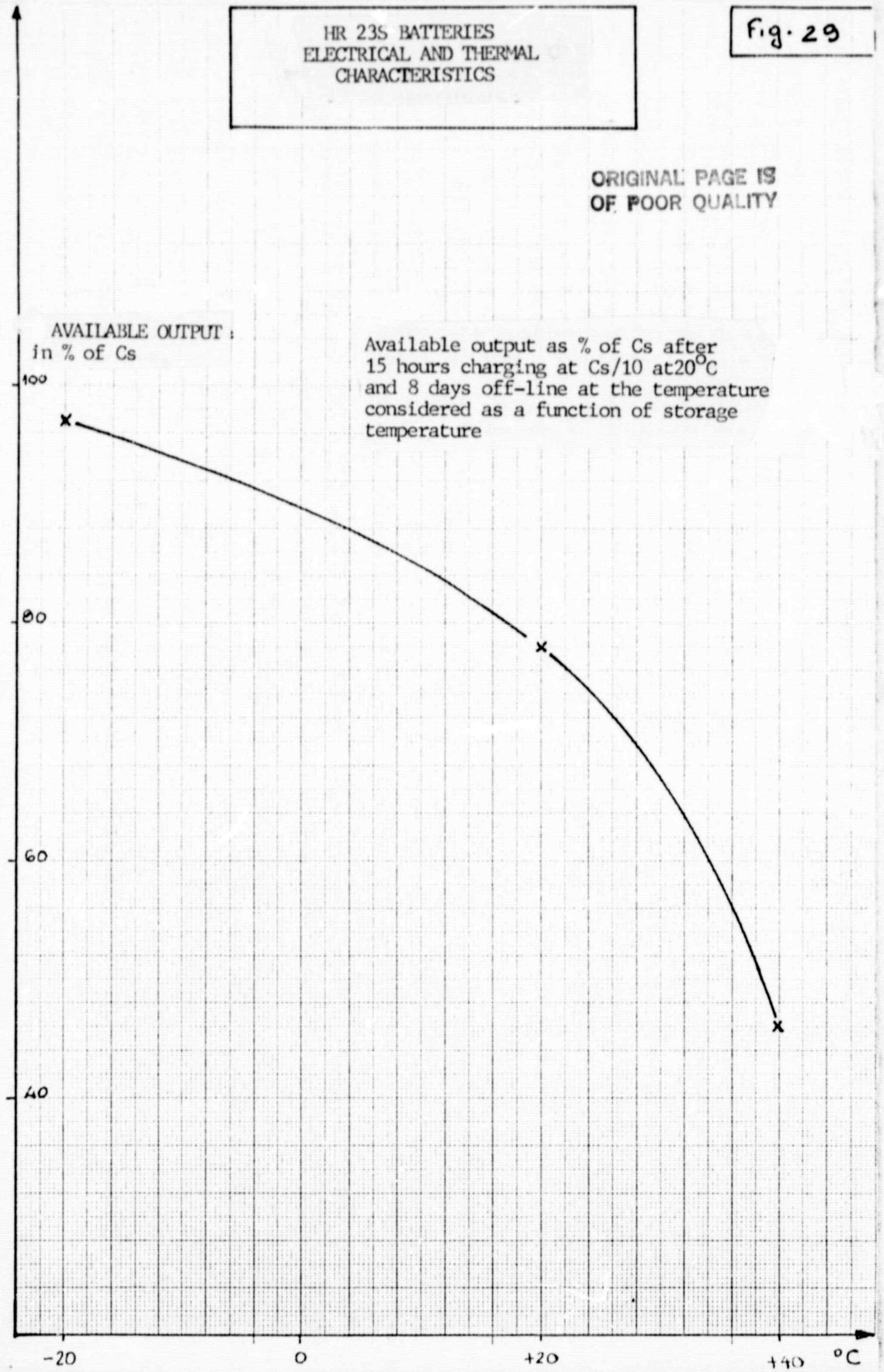

HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS
AVAILABLE OUTPUT :
in % of Cs
Available output as % of Cs after
15 hours charging at Cs/10 at20°C
and 8 days off-line at the temperature
considered as a function of storage
temperature
100
80
60
40
-20
0
+20
+40
°C

Fig. 30

HR 23S BATTERIES
ELECTRICAL AND THERMAL
CHARACTERISTICS